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Currents Through the Golden Gate

by

Ernest Paul Petzrick
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1982

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND PHYSICAL OCEANOGRAPHY

from the

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September, 1993

Curtis A. Collins, Chairman, Department of
Oceanography

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Mean flow and transport were directed at 110°T at 23 cm/s and 45 m^3/s; indicative of the two dimensional structure of the Golden Gate. Mean energy fluxes at the site were 3×10^4 W for kinetic energy advection and 8.5×10^6 W for the work done by pressure. If representative of the channel, they imply a total energy flux of 8.5×10^9 W through the Gate.

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I. INTRODUCTION

The Golden Gate is the narrow, deep channel that connects California's largest and most complex estuary to the Pacific Ocean (Figure 1). The Golden Gate is relatively narrow and deep, 1 km and 110 m, and has an along channel length of 5 km (Figure 2). This is considerably deeper than the sill depth of 7 to 10 meters which lies at the western entrance to the Golden Gate. A navigational channel aligned with the natural channel is maintained at about 0.6 km wide and 20 m deep through the sill. Immediately to the east of the Golden Gate, the tidal channel diverges into northerly and southerly branches. The 20 meter isobath associated with these channels extends south to Yerba Buena Island and north to Carquinez Strait.

The Golden Gate serves a volume of 6.66 X 10^9 cubic meters with a tidal prism of 1.59 X 10^9 cubic meters (Edmonston & Matthew, 1931). The combined effects of large tidal exchange forced by mixed-semidiurnal tides and winds through this narrow channel results in complex subtidal, residual, and bathymetric steering events. Some seiche related forcing is also felt in the Gate from the Central San Francisco Bay (Edmonston & Matthew, 1931). Since the Golden Gate is nearly east/west aligned as is the

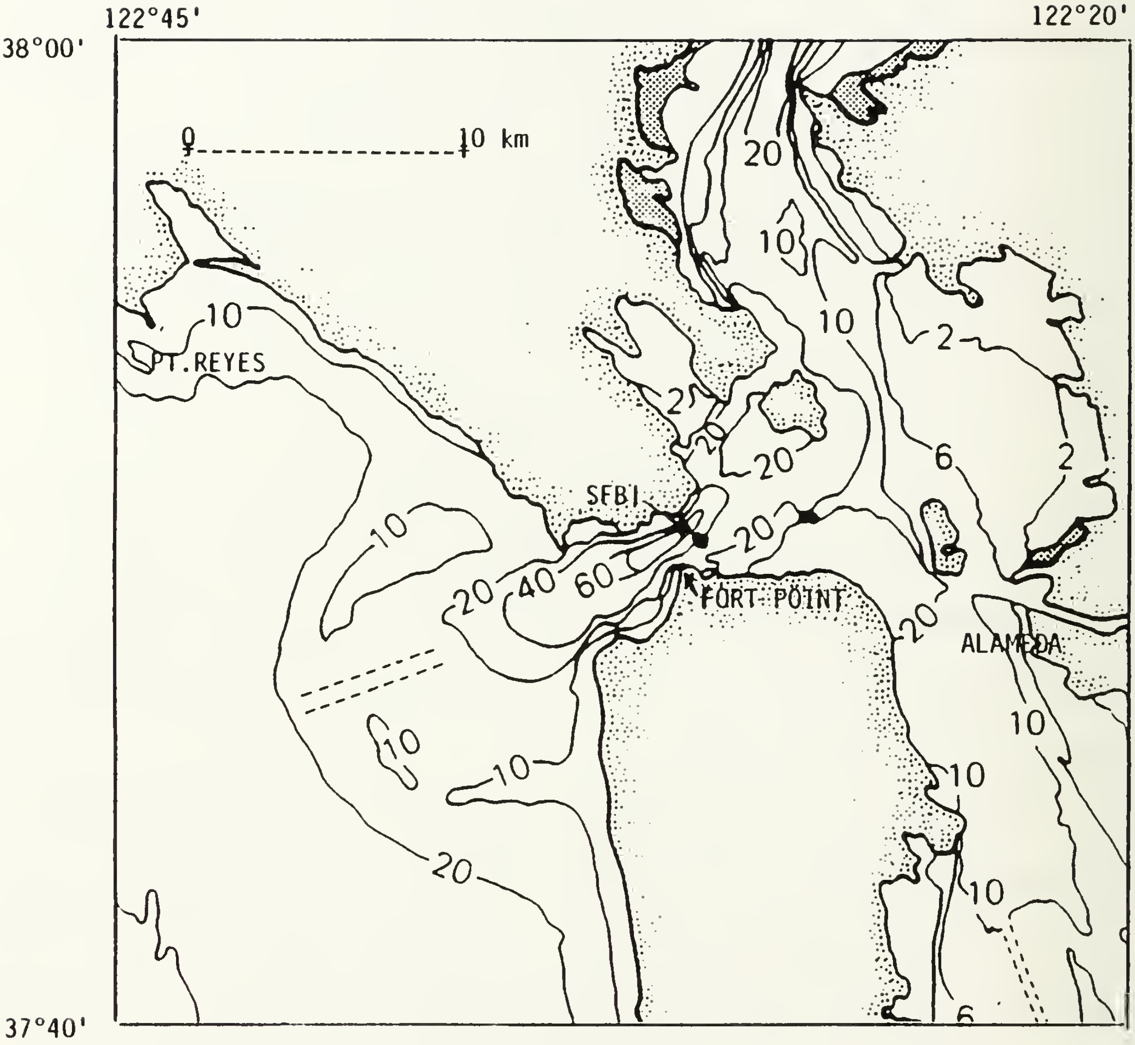
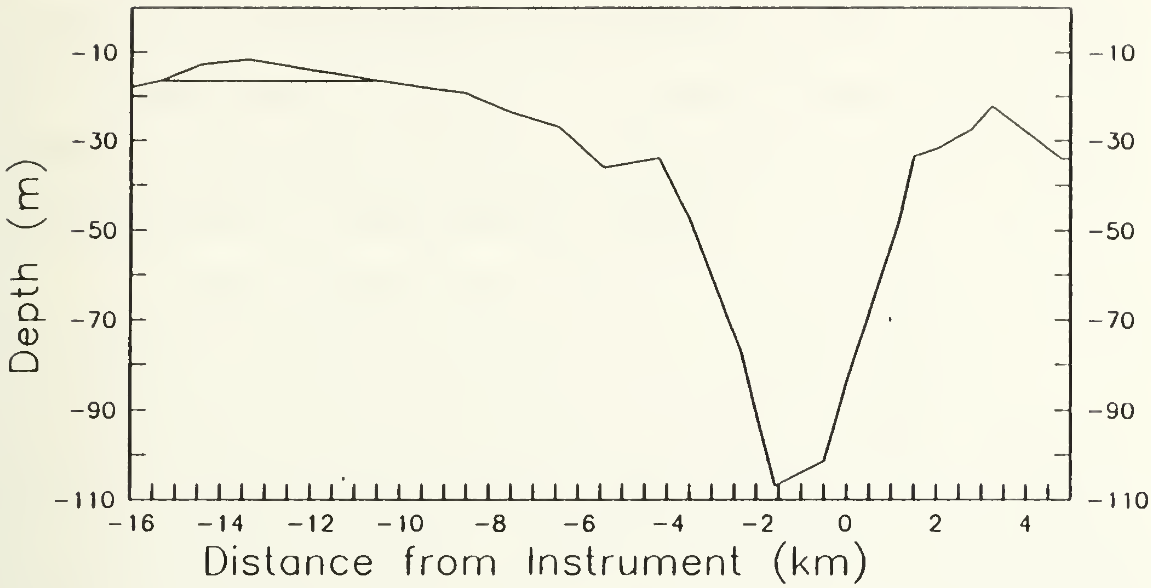


Figure 1. San Francisco Bay and sites of interest.

Along Golden Gate



Across Golden Gate

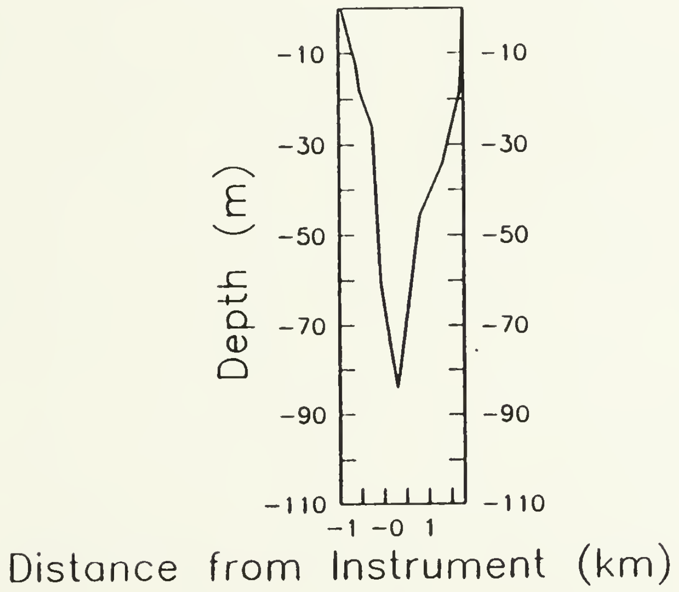


Figure 2. Along and Cross Channel Bathymetric Profiles.

predominate meteorological wind forcing, strong winds can significantly influence the character of the current structure through the Gate (Edmonston & Matthew, 1931). Despite the narrow channel, the southern side of the Gate tends to have more influx than the north. Also seen is the formation of a jet during the flood tides as large volumes of water are forced through the confined channel entering the San Francisco Bay (Conomos and Gartner, 1985).

This study was motivated by several scientific and military factors. First, a NOAA survey to improve tidal current predictions for San Francisco Bay failed to obtain data for the Golden Gate region. Second, NPS has been involved in a study of the oceanography in the Farallones and data from the Golden Gate would provide information on how conditions in the Bay affect those offshore. Lastly, with the U.S. Navy now focused on coastal operations, the dynamics of shelf-estuary interaction need more thorough understanding. On the estuarine side, one of the critical variables of estuarine flow is the buoyancy flux from the ocean and estuary. Seaward, low salinity estuarine waters create plumes and drive coastal currents, significant in coastal minesweeping, antisubmarine warfare, and amphibious operations. Estuary inflow at depth represents a local withdrawal from coastal waters that can dominate low level flow 30 to 50 kilometers from the mouth. Of greater scientific value is the better understanding needed in areas of highly three dimensional, topographically complex flow for advanced estuarine models. One of the most glaring needs is in the modeling of estuaries, where knowledge of the exchanges and flows near the entrance are crucial in setting the proper boundary conditions, which in turn, can dominate the internal calculations.

II. OBSERVATIONS

A RD Instruments self contained acoustic doppler current profiler (ADCP) (operating at 307 KHz, sampling rate is 1 Hz and average data are stored every 3 minutes) and a portable Seabird conductivity, temperature, and depth (CTD) recorder (sampling rate is once every 2 minutes) were deployed inside the Golden Gate from 9 November to 15 December, 1992. Instrument details are provided in Appendix A. The ADCP and CTD were mounted in a steel protective cage and held to a concrete anchor with two acoustic releases mounted in series. The package was deployed from the U.S. Coast Guard Buoy Tender, USCG Blackhaw just inside and to the south of the main navigational channel of Golden Gate at 37° 49.0'N, 122° 28.0'W. This location is designated SFB1. The package was originally placed in 100 meters of water but was dragged by a fishing vessel on 11 or 12 November to 91 meters of water very near the original placement.

Two CTD profiles were recorded near the deployment site using an additional hand tended Seabird CTD (sampling rate every 30 seconds). The first was recorded on 9 November, 1992 from the USCG Blackhaw after deployment of the mooring package. The second profile was recorded on 04 December, 1992 during a slack-to-flood period from a small boat. A recovery profile was not obtained.

Local winds were provided by the Golden Gate Bridge Authority using a National Weather Service anemometer located 267 ft above the water on the Golden Gate Bridge central span. Hourly water level data were obtained from NOAA at San Francisco, Ca., Alameda Ca., Point Reyes Ca., and Port Chicago, Ca., for comparative studies. Meteorological data was also obtained from NAS Alameda. Finally, USGS provided hourly surface temperature and salinity records from Ft. Point, approximately 914 meters to the southwest of SFB1.

III. RESULTS

A. WATER PROPERTIES

Estuaries fed by freshwater rivers at the head and salty oceans at the mouth were believed to have a characteristic profile and flow pattern (Gross, 1993, and Thurman, 1993). The classic method of estuary description has been the strength of stratification between the fresh outflowing surface waters and the salty inflowing deep waters (Stommel, 1951). Golden Gate's estuarine profile was established by comparison of two CTD casts and the time series data of the moored CTD with surface temperatures and salinities measured at Fort Point. The CTD profiles revealed a three layered estuarine profile on 09 November and a more typical two layer profile on 04 December. Salinity, temperature, and density of both profiles were compared and displayed as Figure 3. In the month between profiles, the water cooled by 1° C and freshened by 1.2 psu. The profile measured cooling and freshening was confirmed by the moored CTD and Ft. Point surface data.

The natural freshwater inflow from rivers was highly controlled by dams and dikes constructed for flood control and freshwater conservation. The occurrence of large rainfalls or water released from dams was crucial to better

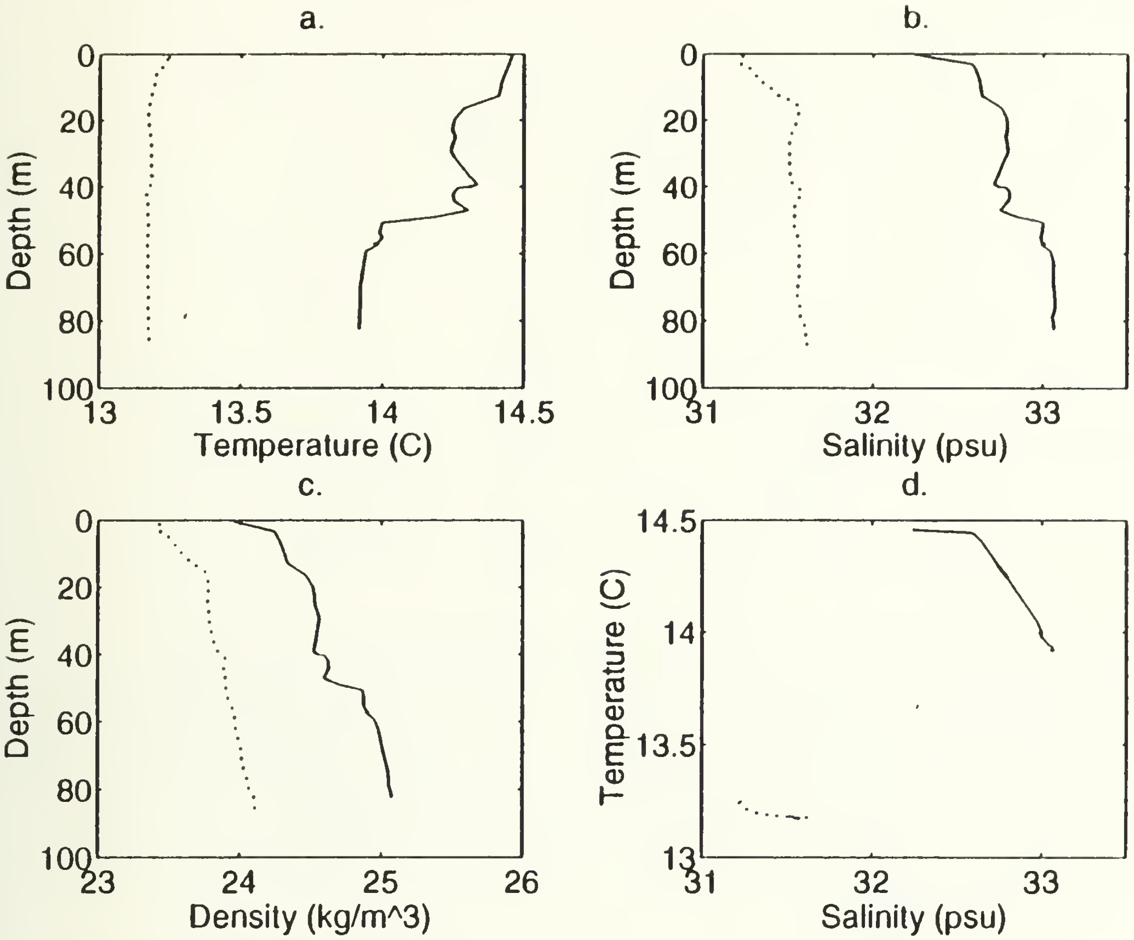


Figure 3. CTD profiles from the Golden Gate
Solid line is 9 November cast.
Dotted line is 4 December cast.

- a. Temperature
- b. Salinity
- c. Density
- d. Temperature vs Salinity

understanding the observed salinity and temperature data. Weather data from the Naval Air Station at Alameda indicated several rain events occurred during the deployment as listed in Table 1.

TABLE 1.
DAILY AVERAGED RAIN FALL (DURATION AND AMOUNT)
AT NAS ALAMEDA

19 Nov	6 hours	0.14"
21 Nov	6 hours	0.03"
22 Nov	8 hours	0.04"
24 Nov	1 hour	0.01"
02 Dec	15 hours	0.71"
05 Dec	7 hours	0.08"
06 Dec	16 hours	0.74"
07 Dec	5 hours	0.08"
08 Dec	15 hours	0.47"
09 Dec	16 hours	0.59"
10 Dec	11 hours	0.36"
11 Dec	6 hours	0.19"

Information from Dr. Smith, USGS, indicated a major freshwater event started about 5 December, peaked about 13 December at 800 m^3/s, and ended on 22 December. The source was approximately 100 kms from Golden Gate.

1. Profile 1

On 09 November, the day of deployment, a relatively shallow warm and fresh surface layer extended to 1 meter. A shallow halocline extended from 1 to 3 meters. In the shallow halocline the salinity gradient approached 0.11 psu/meter, changing from 33.24 psu at 1 meter to 33.58 psu at 3 meters. A shallow thermocline was found at the same depth with a temperature gradient of -0.01 ° C/meter. The resulting pycnocline density gradient approached 0.09 kg/m^3, with a maximum of 24.27 kg/m^3. The midlayer ranged from 3 to 47 meters deep. In this midlayer salinity, temperature, density averaged 33.80 psu, 14.41 ° C, and 24.51 kg/m^3. Two distinct density inversions existed in the midlayer. Density inversions are not unexpected in an area of such strong advection and turbulence. A second or deep halocline extended from 47 to 51 meters. Here the salinity gradient measured 0.07 psu/meter, the temperature gradient -0.08° C/meter, and density gradient 0.06 kg/m^3. The deep saline water extended from 51 to 84 meters. Weak density inversions were again observed in the deep layer. An average salinity increase with depth for the deep layer was 0.002 psu/meter or nearly isohaline with an average of 33.07 psu. Maximum salinity was 33.07 psu. The deep layer temperature and density were 13.92 ° C and 25.07 kg/m^3.

2. Profile 2

The second profile was collected during a slack water period going into a flood condition on 04 December, 1992. The fresh surface layer extended to 4 meters deep with an average salinity of 31.23 psu. Temperature and density in the surface layer were 13.22 ° C and 23.43 kg/m^3. A strong shallow halocline then extended from 4 to 16 meters. The salinity gradient, 0.03 psu/meter was weaker than both the deep and shallow haloclines of 09 November. The thermocline was -.01 ° C/m. The density gradient from the resultant pycnocline was -0.03 kg/m³/m. The deep saline water, 16 to 86 meters, was nearly isohaline with a slight increase with depth and some levels of density inversion. The deep layer salinity range was 31.51 psu and 31.62 psu, with an average of 31.56 psu. The temperature throughout the deep layer was almost a constant 13.18 ° C. Deep layer density averaged 23.94 kg/m³. The deep layer density increased with depth: maximum density 24.14 kg/m³ at 86 meters, minimum density 23.77 kg/m³, for a gradient of 0.01 kg/m³/m.

3. Moored CTD

The moored CTD confirmed an overall freshening and cooling trend during the deployment. Pressure data from the CTD was used for tidal height analysis.

a. Temperature

The moored CTD revealed an overall cooling during the deployment. Figure 4a, 2 minute temperature data, clearly shows temperature oscillations of about 0.5 ° C amplitude imposed on a general cooling through the record. The temperature oscillations are dampened by twenty seven days into the record. The maximum temperature, 15.97 ° C, was observed during the first day. At day twenty eight, a short but strong warming is noted and oscillations return.

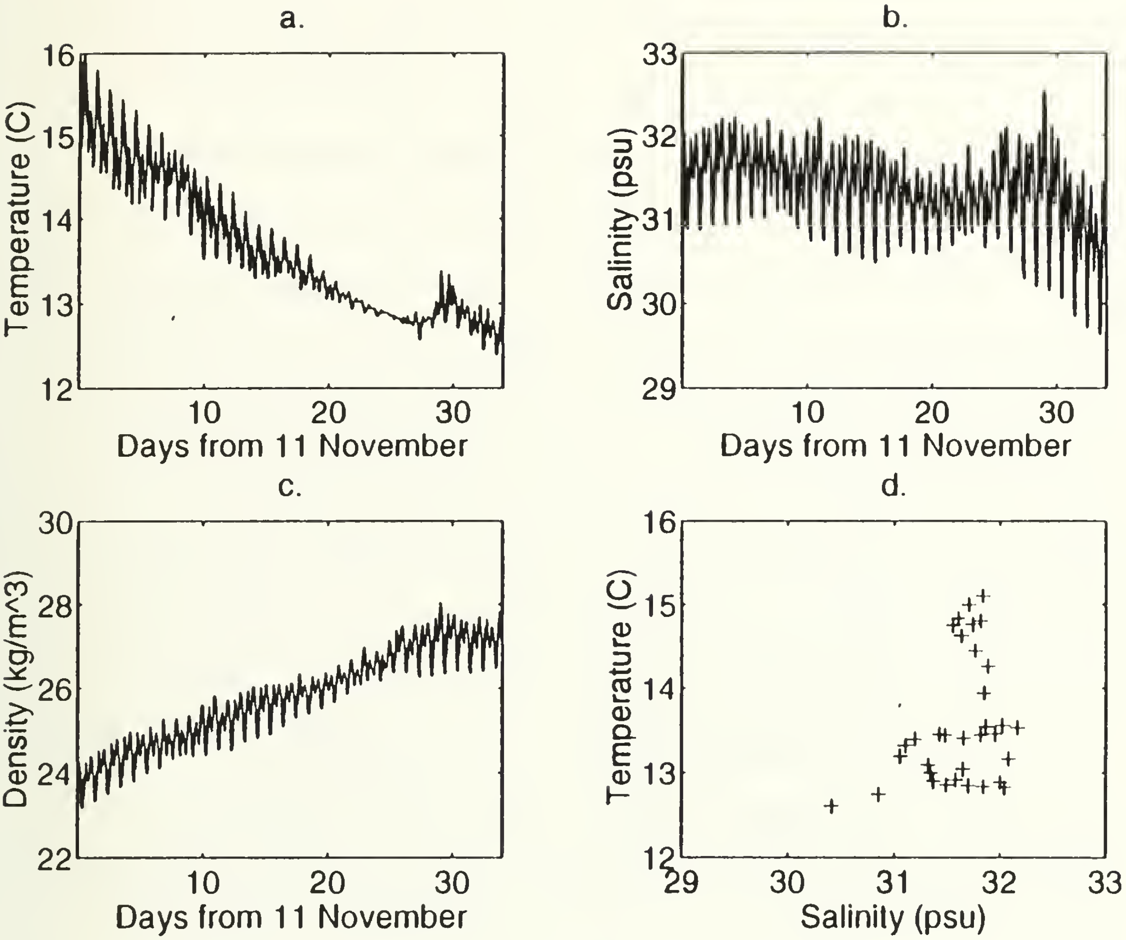


Figure 4. Near bottom CTD data from 1500Z 11 November to 1500Z 15 December for the Golden Gate.

a. Temperature
b. Salinity
c. Density
d. Daily Temperature vs Salinity

The temperature soon settles back to a cooling trend. The minimum temperature was 12.40 °C on the last day. Average temperature through the deployment was 13.63 °C with a standard deviation of 0.81 °C.

b. Salinity

The salinity, Figure 4b, maintained an oscillation of about 0.5 psu throughout the record. A slight freshening trend through the first twenty seven days is amplified during the last seven days of the record. The enhanced freshening from day twenty-eight through the end of the record coincides with the warming pulse described in the temperature signal. The salinity had a maximum of 32.53 psu and a minimum of 29.63 psu, with an average of 31.36 psu and a standard deviation of 0.42 psu.

c. Density

The density showed oscillations on the order of 0.5 kg/m^3. The first twenty seven days of record demonstrated a general density increase with time on the order of 0.11 kg/m^3 per day for a rise of over 3 kg/m^3. During the remaining seven days of the record, the density seemed to oscillate about an average of 27.21 kg/m^3.

d. Temperature vs Salinity

Figure 4d clearly shows the general cooling and freshening had two distinct phases. The first phase occurred during the first twenty seven days of the record.

During the first phase the salinity change was slow, on the order of 0.5 psu, whereas the temperature change was rapid, nearly 3 ° C. During second phase the roles were reversed. Salinity changed rapidly, on the order of 1.0 psu in 5 days, with temperature cooling only slightly, less than 0.5 ° C.

e. Heights

Strong tidal forcing was considered the primary energy source for the Golden Gate. Tides created changes in sea level and water flow through the Golden Gate. Determination of tidal influence on water heights was essential. Sea level height was analyzed using the bottom pressure measured by the moored CTD, Figure 5. No corrections were applied to the pressure data to compensate for variations in atmospheric pressure or the changes in water density. Tidal analysis and prediction was accomplished through the use of least squares harmonic analysis routines (Foreman, 1977). Complete Foreman analysis and details are included as Appendix B. From 33 days of record, 39 constituents were derived. Of the 39 derived constituents the nine largest tidal contributors are six of the primary constituents, O1,P1,K1,N2,M2,and S2, one of the overtide constituents, M4, and two of the compound tides, MK3 and 2MK5 (see Table 2).

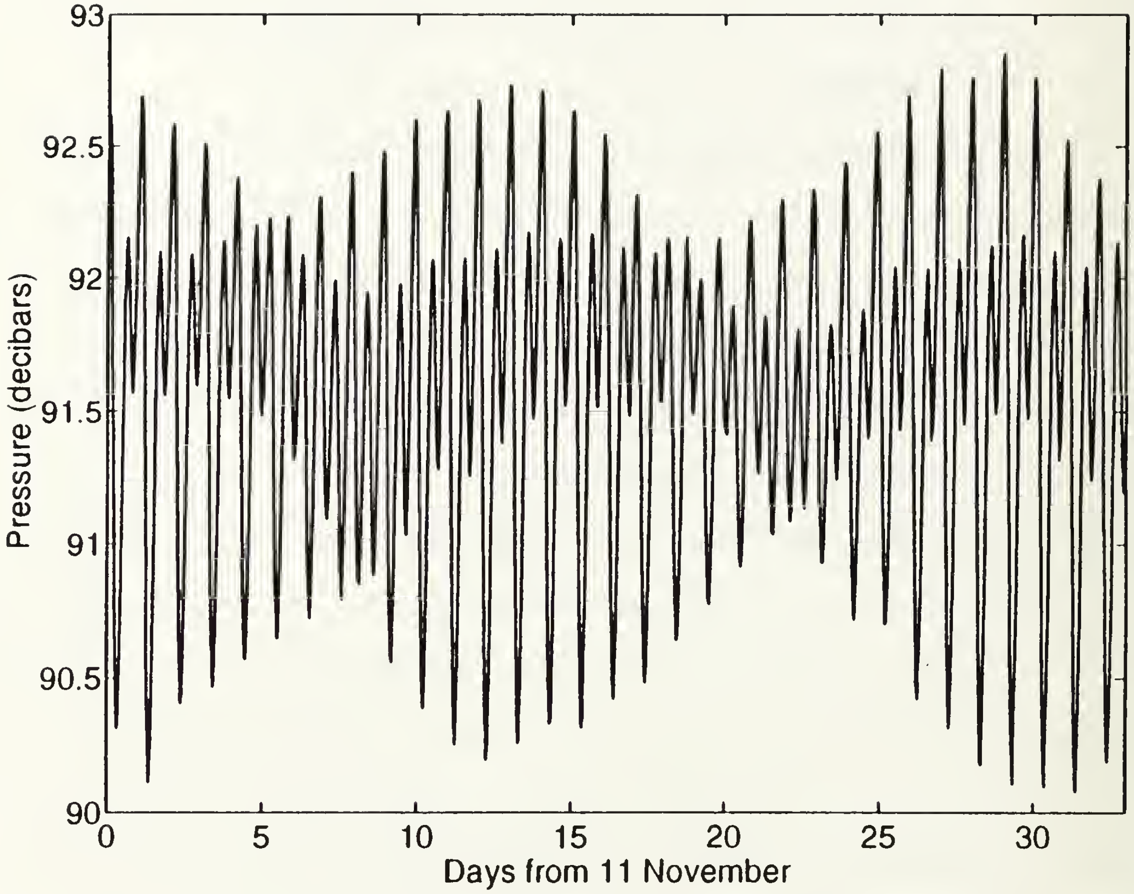


Figure 5. Near bottom CTD Pressure, decibars (10^4Pa), for the Golden Gate.

TABLE 2

MEANS AND STANDARD DEVIATIONS OF TIDE HEIGHT CONSTITUENTS
Amplitude and phase have been corrected for Nodal effects.
Amplitude expressed in meters, phase shift in degrees.
Standard deviation for amplitude means were all 0.02.

	Amplitude	Phase Shift	
	mean	mean	std
O1	0.25	301.4195	2.6952
K1	0.47	313.8095	2.9338
N2	0.09	10.4635	2.9338
M2	0.59	36.8960	5.7998
S2	0.11	41.6140	5.8655
MK3	0.02	50.5475	10.4027
M4	0.02	158.7485	12.4486
2MK5	0.01	123.6490	18.3325
M6	0.01	214.3805	44.2597
3MK7	0.01	210.9190	53.2599

The moored CTD pressure signal yielded tidal constituents consistent with those derived by NOAA for San Francisco Bay (see Appendix B). Diurnal and semidiurnal tides are commonly referred to as "primary tides". In shallow waters the tidal wave becomes asymmetric, and this effect is approximated by using harmonics of the fundamental period. This affect is similar to the overtones in music, thus giving the name "overtides" to constituents such as M4 and M6. Other shorter period tides are very closely related in frequency so they are commonly lumped together and referred to "compound tides" (Dronkers, 1964 and Schureman, 1958). Overtides and compound constituents can also be lumped together under the term "Shallow Water Constituents". (Dronkers, 1964 and Schureman, 1958 and 1976).

The significant tidal constituents in this analysis are listed in Table 3 with their period and celestial origin.

TABLE 3
MAJOR HARMONIC TIDAL CONSTITUENTS ANALYZED AT SFB1
(Godin, 1972, Dronkers, 1964, and Schureman, 1958 and 1976)

Constituent	Period(hrs)	Origin
O1	25.82	Principal Lunar
P1	24.07	Principal Solar
K1	23.93	Principal Luni-Solar
N2	12.66	Larger Elliptical Lunar
M2	12.42	Principal Lunar
S2	11.99	Principal Solar
MK3	8.18	M2+K1
M4	6.21	2M2
2MK5	4.93	2M2+K1
M6	4.14	3M2
3MK7	3.53	3M2+K1

The largest tide was the M2 at 0.590 m. The sum of the principal diurnal tides, O1 (0.247m) and K1 (0.367m) was just larger than the M2 constituent. N2 and S2 contribute 0.092 m and 0.136 m respectively. P1 was inferred from the K1 constituent at 0.121 m. The amplitude of the M4 overtide was 0.024 m. The compound tides MK3 and 2MK5 contribute 0.021 m and 0.010 m respectively.

f. Frequency Response

I also carried out least squares analysis for temperature and salinity data. Results for the five largest constituents are listed in Table 4. Compared to pressure results, it is clear that harmonic analysis fails to resolve the semidiurnal and diurnal energy present in these records.

TABLE 4

HARMONIC ANALYSIS OF TEMPERATURE AND SALINITY

Amplitude of temperature is ° C.
Amplitude of salinity is psu.

Constituent	Temperature	Salinity
O1	0.13	0.01
K1	0.67	0.22
N2	0.58	0.06
M2	0.91	0.35
S2	0.27	0.07

This is because the temperature and salinity gradients are changing with time and smearing the energy over a broader band. To compare the variability in the CTD data as a function of frequency, the spectral magnitudes of temperature, salinity, and pressure data were compared and displayed in Figure 6. The signal with the greatest amplitude is the pressure signal. The pressure signal clearly showed two diurnal and two semi-diurnal tidal spikes. There was relatively little spectral energy below the diurnal frequencies in the pressure data. Salinity had the next greatest magnitude response. Diurnal and semi-diurnal spikes were the dominant features of the salinity spectrum. The salinity low frequency energy was greater than the pressure signal. Temperature response had an extremely strong signal in the very low frequency range, far exceeding the diurnal and semi-diurnal response. The temperature also had significant diurnal and semi-diurnal peaks.

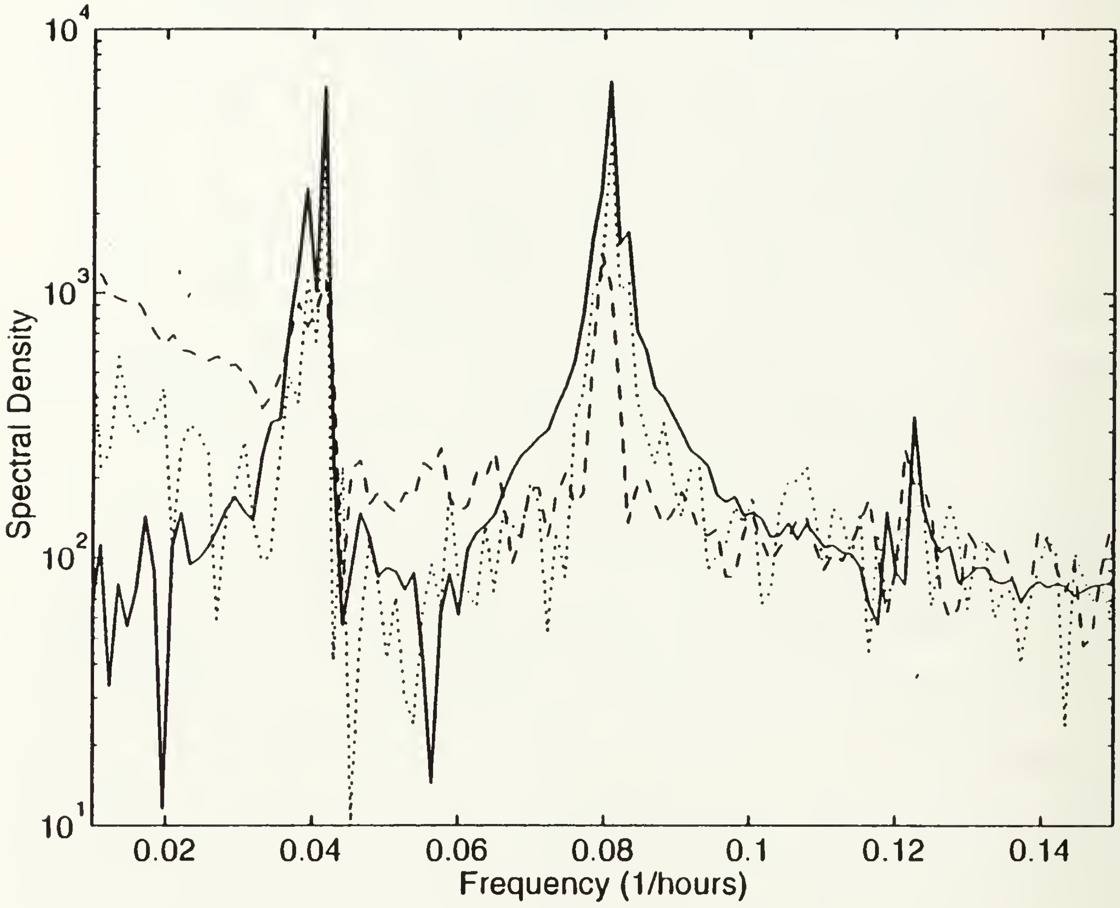


Figure 6. Spectral Density of Near Bottom CTD Pressure (solid), Temperature (dashed), and Salinity (dotted).

Diurnal temperature response while not as peaked as the salinity was much broader indicating a more energetic response.

4. Surface vs Subsurface Comparison

The gradients of temperature and salinity with depth were considered critical to understanding the natural restoring forces of the Golden Gate waters. Half hourly temperature and salinity data from the moored CTD was compared to half hourly surface, temperature and salinity, data recorded at Ft. Point, approximately 914 meters southwest of SFB1, by USGS, Figure 7.

Surface temperatures were warmer than subsurface temperatures on 11 November, 1992 by 0.45 ° C. The temperature difference decreased through the deployment until 11 December, 1992. On 11 December the temperature gradient reversed, surface temperatures were slightly colder than at depth. The temperature inversion, order 0.1 ° C, remained through instrument recovery, 15 December, 1992.

Although the surface salinity measurements failed on 25 November, the surface and subsurface salts appear to merge during the first two weeks of subsurface measurements indicating freshening subsurface or saltier surface waters. The Fort Point salinity measurements did not resume until the day that we retrieved the ADCP. At that point, they confirmed the freshening trend that occurred at depth.

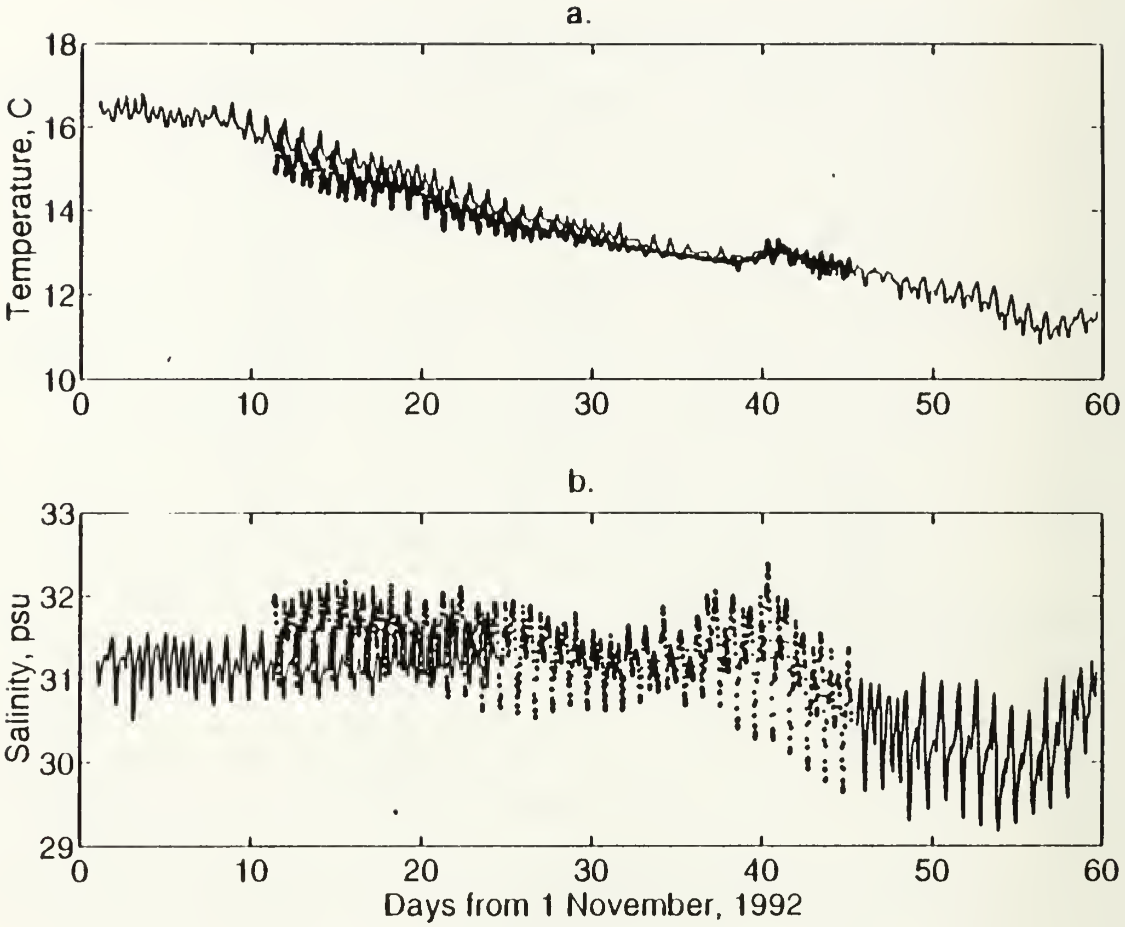


Figure 7. Near bottom and Surface Temperatures and Salinities for the Golden Gate. Surface measurements from Fort Point were provided by USGS. Heavy dotted line is near bottom. Light solid line is Fort Point.

a. Temperature

b. Salinity

B. CURRENT ANALYSIS

The measured currents contained mostly tidal energy but several factors --- topography, meteorology, internal waves, and nonlinear response --- influence and modify tidal forces. Separating and studying those signals was the greatest challenge of the data analysis.

1. Mean Flow Statistics

The along channel, U component, and cross channel, V component, show both depth dependent shear and tidal asymmetry. The along channel flow had a maximum (flood maximum), Figure 8, of 218 cm/s at 60 meters depth. The along channel minimum was -173 cm/s, ebbing, at 68 meters depth. The mean flow was flooding the bay with a maximum of 32 cm/s at 20 meters. Cross channel flow maximum, approximately northward flow, was at 12 meters, 69 cm/s, Figure 9. Maximum cross channel flow decreased with depth to a minimum of 46 cm/s at 84 meters. The minimum cross channel (approximately southward) flow had a maximum of 86 cm/s at 36 meters, increasing from 75 cm/s at 12 meters. Minimum cross channel flow then decreased with depth to 62 cm/s at 76 meters and then increased slightly to 66 cm/s at 84 meters. Complete flow statistics were calculated and listed in Table 4.

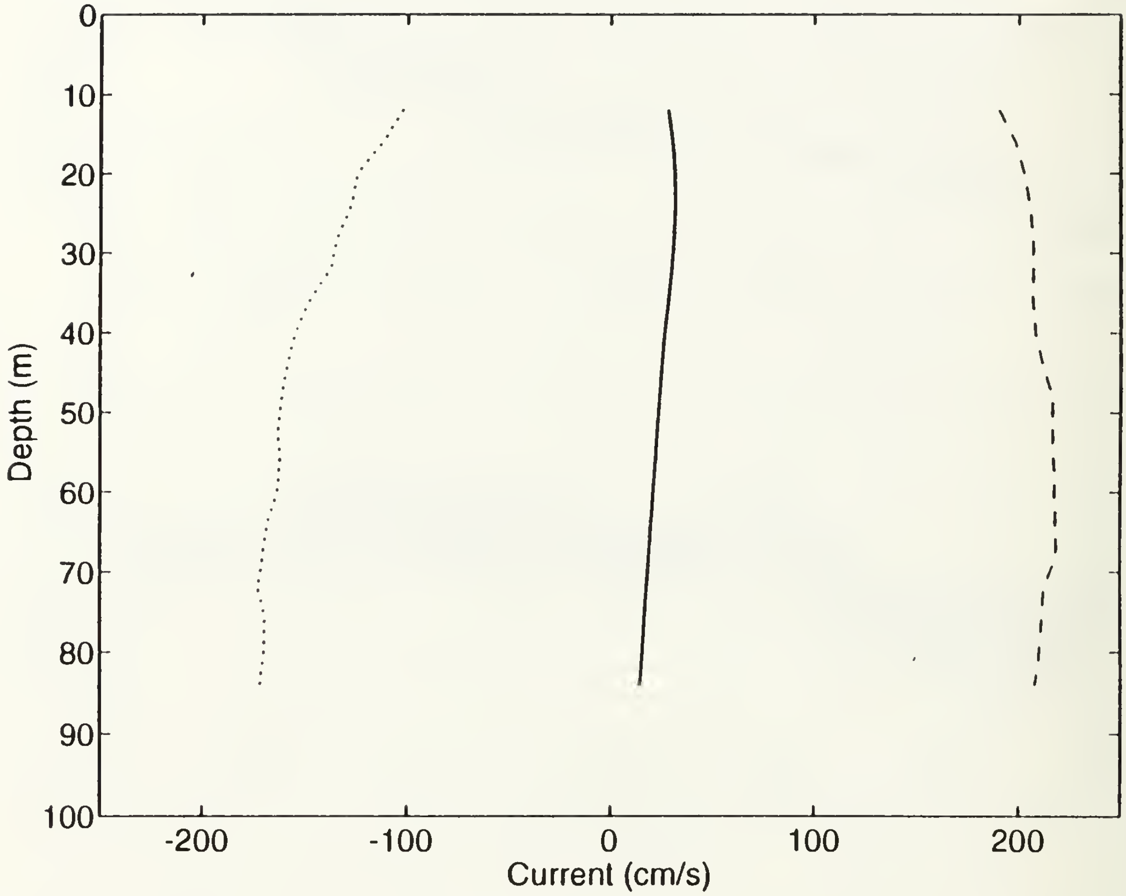


Figure 8. East/West Current Statistics for the Golden Gate. Solid line is average current. Dashed line is maximum current. Dotted line is minimum current.

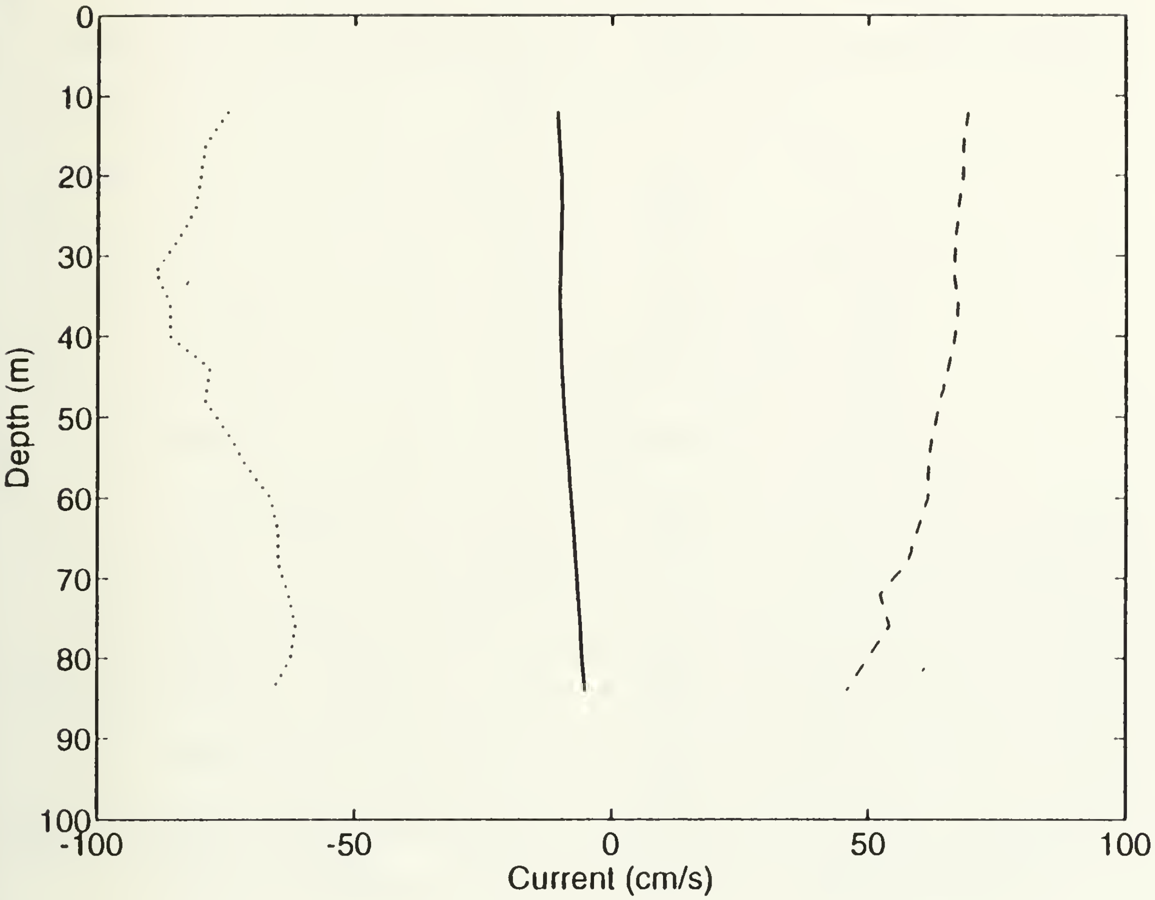


Figure 9. North/South Current Statistics for the Golden Gate. Solid line is average current. Dashed line is maximum current. Dotted line is minimum current.

Maximum and mean along channel flood and ebb were determined from the U and V components, Figure 10. The along channel ebb, Figure 10a, demonstrated depth dependant shear. The mean ebb flow was 61 cm/s with a maximum at 84 meters, 74 cm/s, and a minimum at 12 meters of 36 cm/s. The strongest measured ebb had a similar profile to the mean ebb: maximum at 84 meters, 173 cm/s, minimum at 12 meters, 102 cm/s, with an average of 151 cm/s. The along channel flood, Figure 10b, had minimums at the top (12 meters, 88 cm/s) and bottom (84 meters, 92 cm/s) and a maximum of 105 cm/s at 44 meters depth. The mean flood was 99 cm/s. The maximum flood had a similar profile but its maximum was deeper in the water column, 219 cm/s at 68 meters. Minimums were again at the top and bottom, 190 cm/s at 12 meters and 208 cm/s at 84 meters. Mean current for each depth bin was removed and currents remained "de-meaned" for most of the remaining analysis. Certain energy and flux calculations required the use of non-demeaned signals; means were added back to the signals as required.

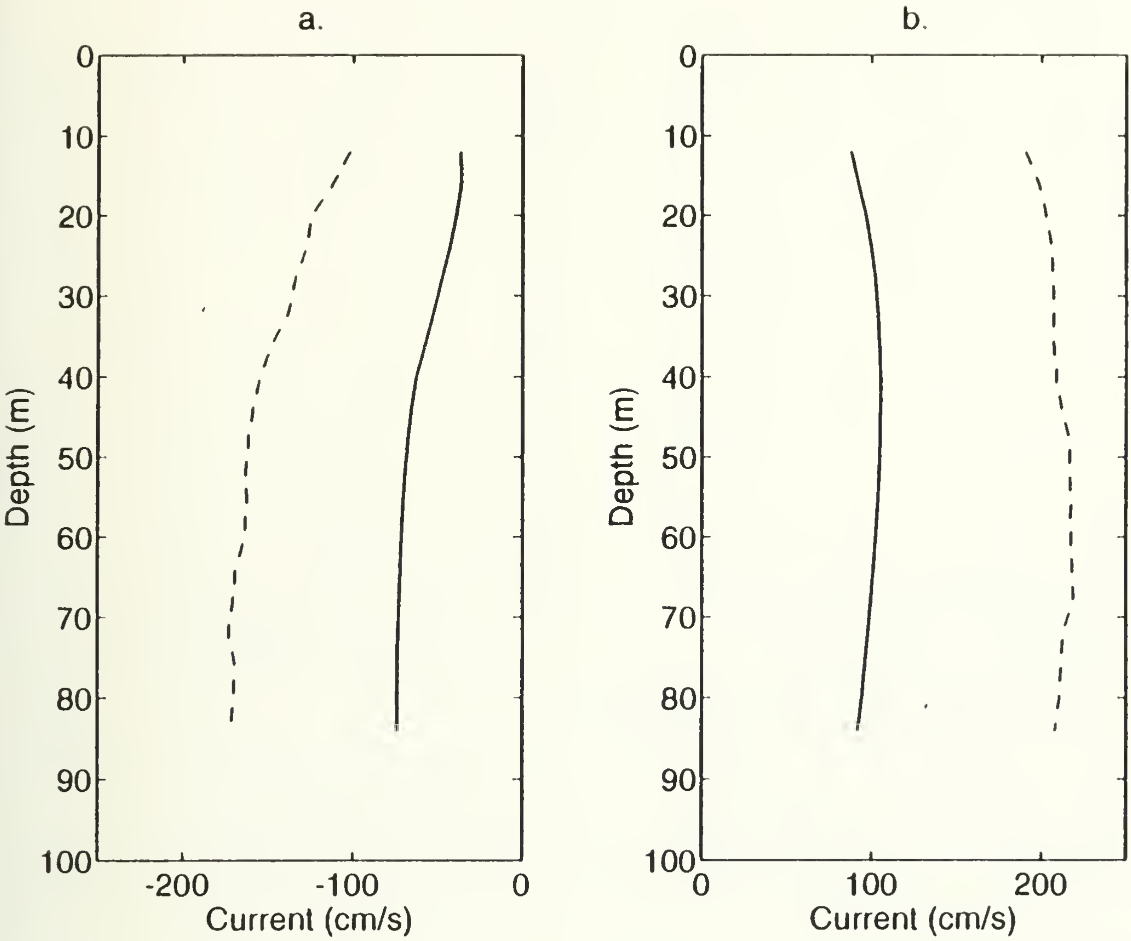


Figure 10. Flood and Ebb Statistics for the Golden Gate. Solid is average current. Dashed is maximum current.

a. Ebb Current

b. Flood Current

TABLE 4
ALONG AND CROSS CHANNEL STATISTICS

depth m	min cm/s	max cm/s	mean cm/s	std cm/s
		Along Channel		
12	-102	190	28	67
20	-125	203	32	73
28	-134	207	31	79
36	-148	207	28	85
44	-159	212	25	90
52	-163	217	23	92
60	-164	218	21	91
68	-173	212	18	91
76	-169	211	17	90
84	-172	208	15	88
		Cross Channel		
12	-75	69	-11	19
20	-80	68	-10	19
28	-84	67	-10	19
36	-86	67	-10	19
44	-78	65	-10	18
52	-75	63	-9	17
60	-66	62	-8	14
68	-65	58	-7	13
76	-62	54	-6	13
84	-66	46	-5	15

2. Principal Axis Rotation

The first step in current analysis was rotation to principal axis. Principal axis rotation was used to minimize variance across one axis which will subsequently be referred to as "across channel". (No attempt was made to rotate coordinates with respect to the vertical axis) Details of principal axis calculation and rotation are included in Appendix C. Principal axis analysis revealed little depth dependency for rotation to principal axis.

Rotation increased from almost 3 degrees at 12 meters depth to a maximum of 8.5 degrees at 44 meters depth then decreased to 2.5 degrees at 84 meters, Figure 11.

3. Scatter Diagrams

The nature of the along and cross channel flow was visualized by scatter plots of the rotated velocity vectors. These plots are drawn by placing a dot at the end of each three minute vector. Scatter diagrams (Figure 12) demonstrated two consistent features: an elongated "S" shaped pattern and variable cross channel flow. In Figure 12a, 12 meters depth, the "S" shaped pattern had less along channel magnitude and considerably greater cross channel flow than those for deeper velocities. A strong northward component in the early stages of the ebb gives way to strong offshore flow with a weak southward component. The flood does not show the same development pattern. The flood develops uniformly and sweeps out a fairly broad pattern of flow into the Bay. In Figures 12b and 12c, 40 and 64 meters deep respectively, the "S" shape is elongated in along channel direction with less cross channel flow. The flood, positive along channel flow, demonstrated less veering than the ebb (negative along channel flow). Although not as dramatic as in Figure 12a the ebb side of the "S" again shows a change in direction from northward components which give way to southward components as the ebb strengthens.

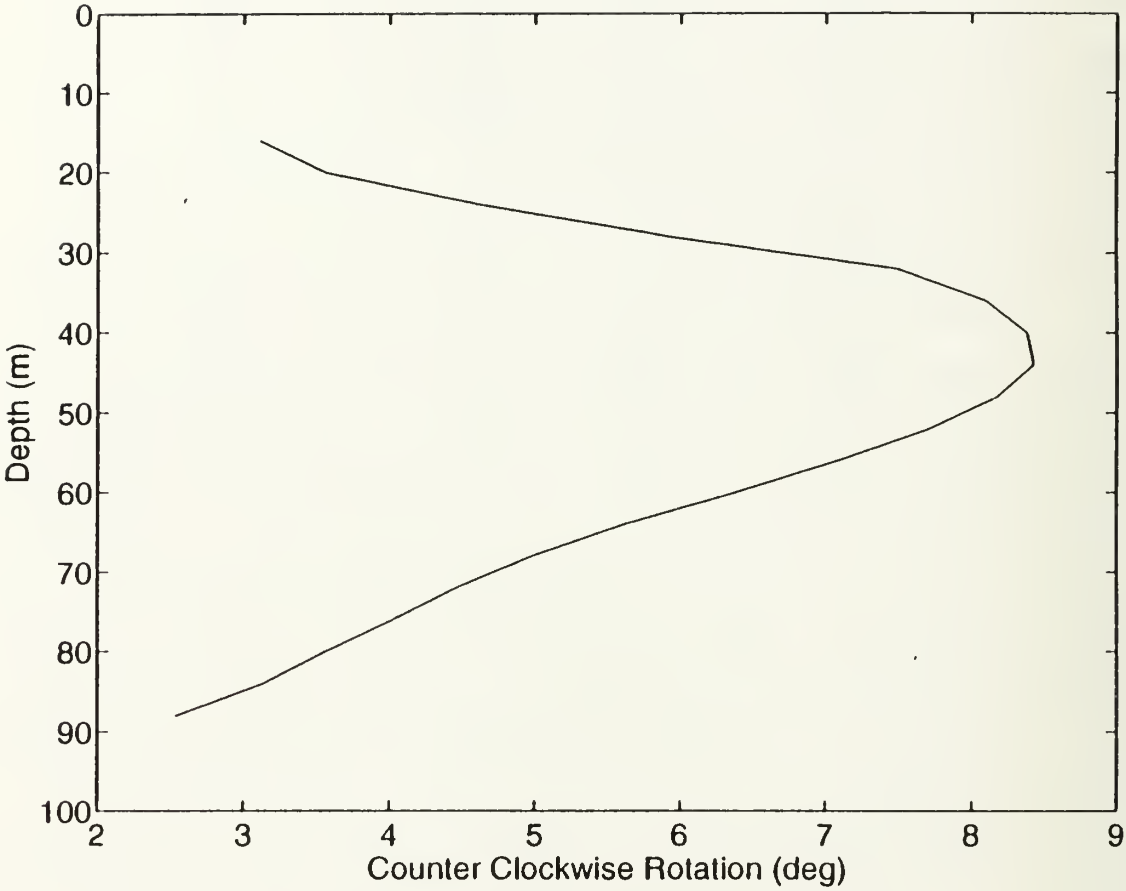


Figure 11. Principal Axis Rotation for Golden Gate Currents.

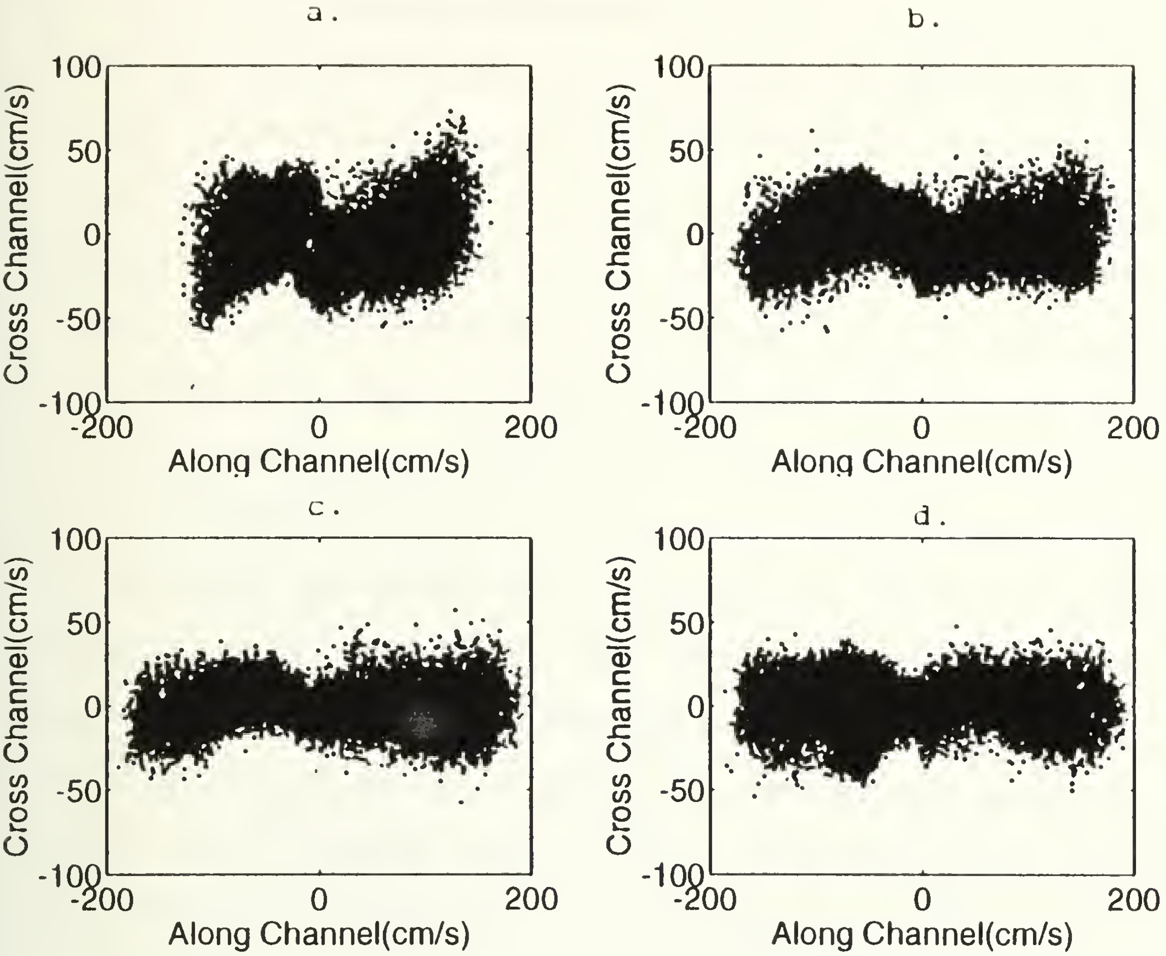


Figure 12. Scatter Diagrams, U vs V for the Golden Gate currents.

a. 12 meters depth
b. 40 meters depth
c. 64 meters depth
d. 84 meters depth

Finally in Figure 12d, 84 meters deep, the "S" shape has broadened and twisted into a flattened "m" shape. Figure 12d shows considerable cross channel dispersion with more pronounced northward flow enhancement on both the flood and ebb flow leading to the "m" shape. The strength of along channel flow at 84 meters is the same as at mid depth.

4. Tidal Analysis

The next step was to determine the tides. A least squares harmonic analysis was completed for the rotated, demeaned currents (Foreman, 1978). Complete listings are included as Appendix B. From 33 days of record, 39 constituents were derived (two by inference) and are in agreement with previous studies (Walters et al., 1985). The larger constituents consisted of five primary constituents (O1,K1,N2,M2,S2), three compound tides (2MK5,MK3,3MK7), and two overtides (M4,M6). Graphical results of semi-major axis, semi-minor axis, inclination in degrees from 090° T, and Greenwich phase lags (G) are represented in Figures 13, 14, 15, and 16. The inclination is the amount, measured in degrees, the semi-major axis is rotated clockwise from the positive X, in this case 090° T. Greenwich phase lag, G, is the interval which the instant of maximum current lags the simultaneous transit of the fictitious developmental stars at the celestial Greenwich (Foreman, 1978). Table 5 summarizes the tidal constituent's semi-major, semi-minor, and inclination by depth. In Figures 13 through 16 and Table 5, a negative semi-minor axis indicates clockwise ellipse rotation. The least squares analysis used hourly three-minute samples; this allowed 20 estimates of each constituent so that standard deviations could be calculated.

The primary constituents were larger in amplitude than the combination and overtides. The diurnal and semi-diurnal tides (K1,N2,M2,S2) all had maximum amplitude at a depth of 68 meters, Figures 13 and 14. The combination tides MK3, 3MK7, 2MK5 and the compound tides M4 and M6 all demonstrate a maximum amplitude near a depth of 24 meters, Figures 15 and 16, which correspond to the upper mixed layer described in the CTD profiles and which is also the dredged sill depth.

a. Lunar Semidiurnal (M2)

The M2 tide was an order of magnitude larger than all other tidal constituents. The semi-major axis was 82 cm/s near the surface, increased monotomically to a maximum of 115 cm/s at 68 meters, then decreased again to 108 cm/s at 84 meters, Figure 13a. The semi-minor axis (Figure 13b) varied by +/- 2 cm/s about an average of 2 cm/s with clockwise sense. When the semi-minor axis is zero, or is much less than the semi-major axis, motion is nearly rectilinear. This is certainly the case for the lunar semidiurnal current.

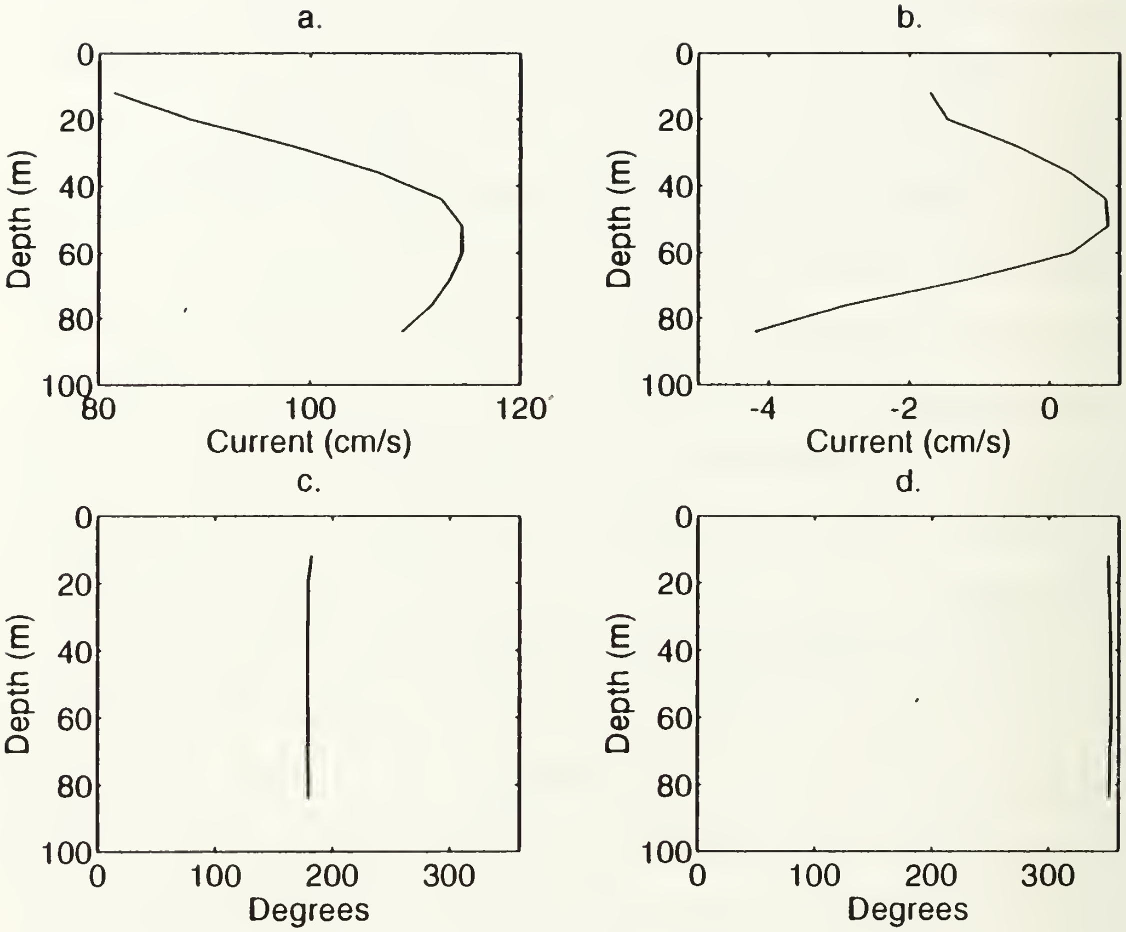


Figure 13. Lunar semidiurnal tidal currents for the Golden Gate.

a. Semi-Major Axis
b. Semi-Minor Axis
c. Inclination from 090° T
d. Phase Shift from Greenwich

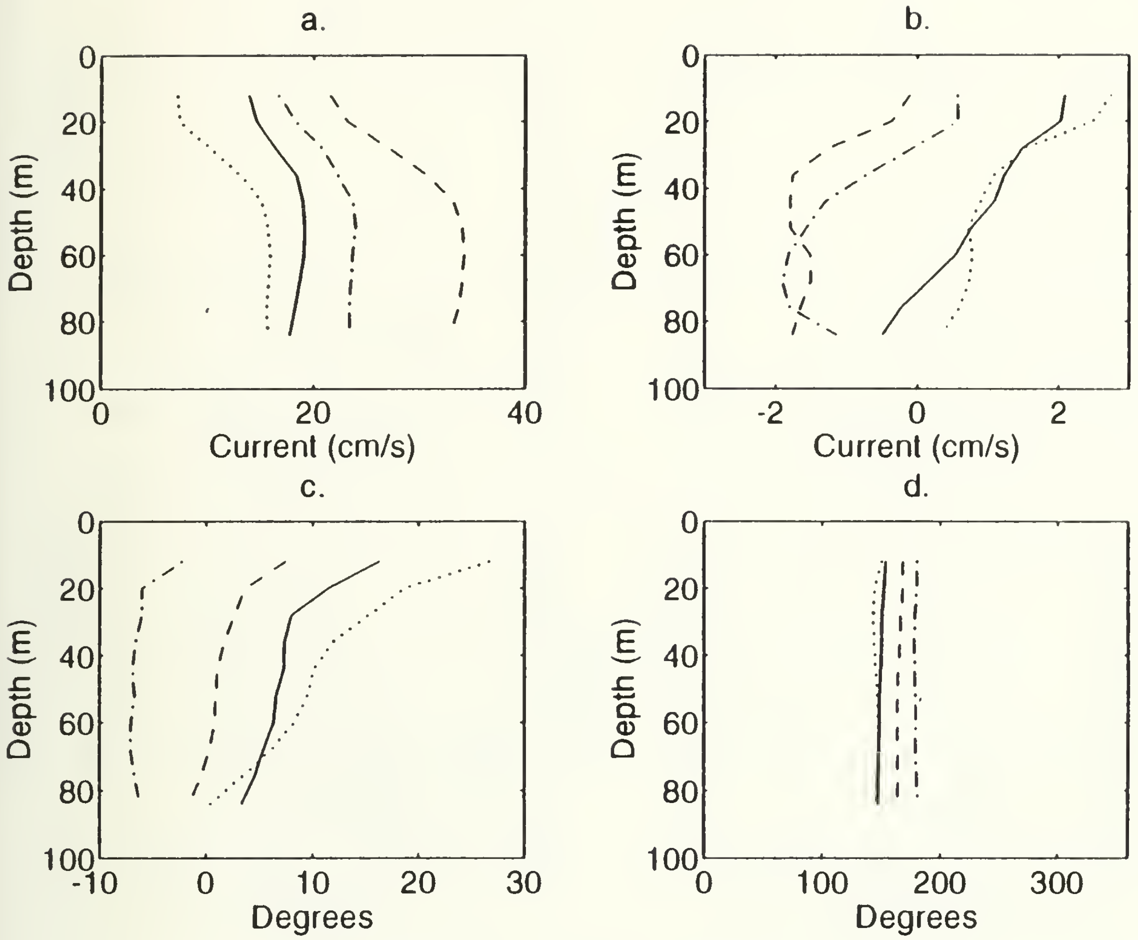


Figure 14. Primary tidal currents for the Golden Gate. Solid line is N2. Dashed line is K1. Dotted line is O1. Dashed-dotted line is S2.

a. Semi-Major Axis
b. Semi-Minor Axis
c. Inclination from 090° T
d. Phase Shift from Greenwich

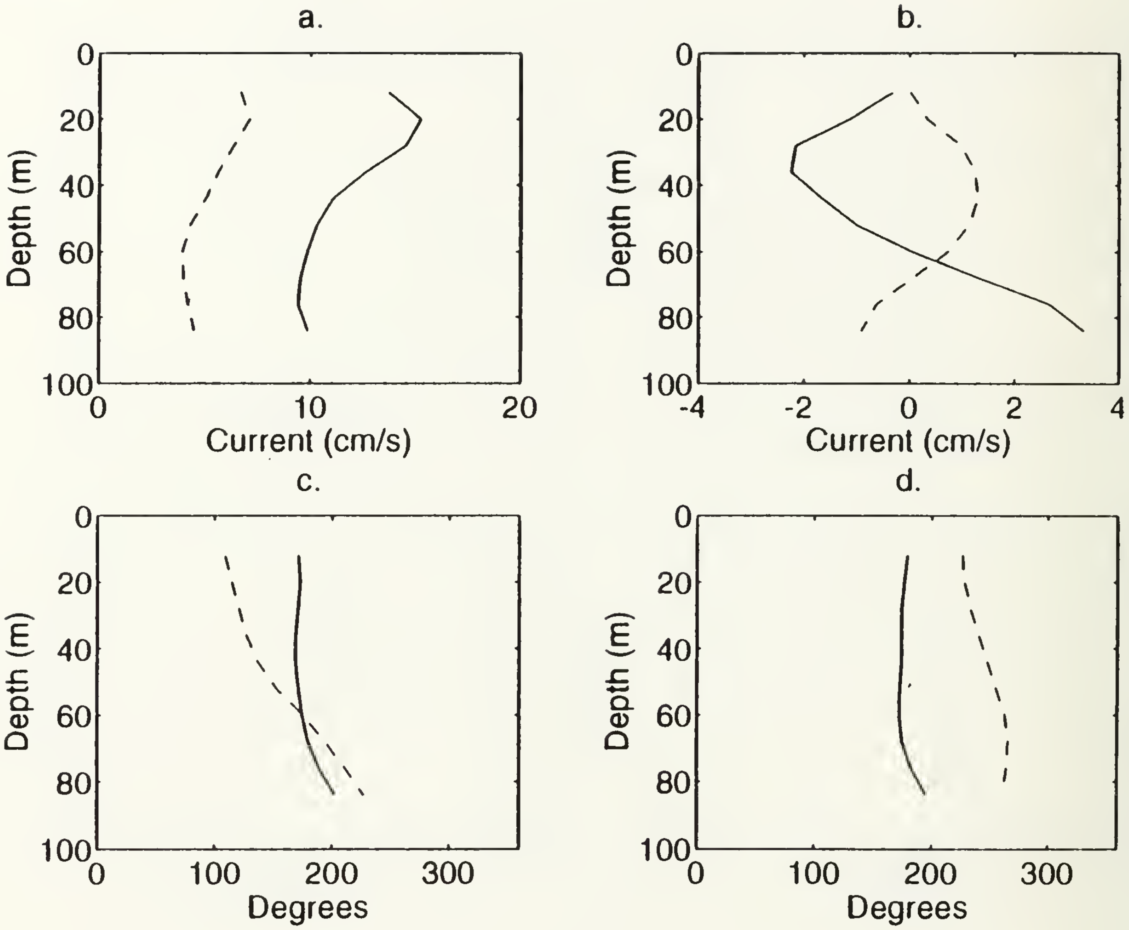


Figure 15. Overtide tidal currents for the Golden Gate. Solid line is M4. Dashed line is M6.

a. Semi-Major
b. Semi-Minor
c. Inclination from 090° T
d. Phase Shift from Greenwich

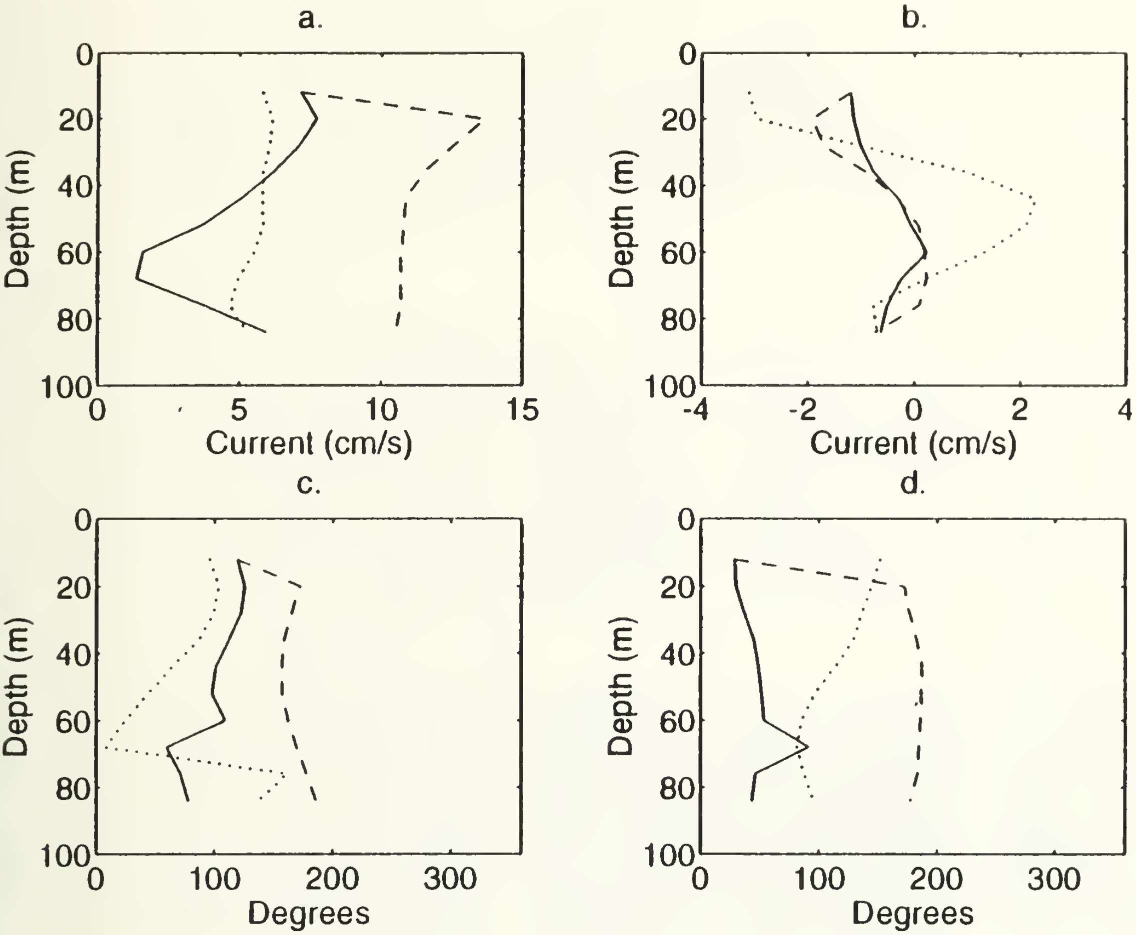


Figure 16. Compound tidal currents for the Golden Gate. Solid line is 3MK7. Dashed line is MK3. Dotted line is 2MK5.

a. Semi-Major Axis
b. Semi-Minor Axis
c. Inclination from 090° T
d. Phase Shift from Greenwich

TABLE 5

TIDAL CURRENT CONSTITUENT STATISTICS

This table lists the mean and standard deviation of the tidal ellipse semi-major axis (cm/s), semi-minor axis (cm/s), inclination from east (degrees), and the phase shift from Greenwich (degrees) with respect to depth, d (meters).

TIDAL CONSTITIUENT: O1

d	semi-major		semi-minor		inclination		G		G+		G-	
	m	std	m	std	m	std	m	std	m	std	m	std
12	7.21	0.52	2.75	0.42	26.73	5.20	150.47	9.23	123.73	6.66	177.19	13.41
20	7.39	0.60	2.49	0.53	18.64	5.30	144.69	9.09	126.05	6.88	163.33	13.19
28	10.38	0.46	1.52	0.48	15.34	3.17	143.29	6.22	127.95	5.74	158.64	8.03
36	13.19	0.44	1.09	0.42	11.92	2.15	144.04	5.21	132.13	5.34	155.94	5.93
44	15.16	0.49	0.89	0.66	10.18	1.85	145.44	4.58	135.27	4.94	155.62	4.94
52	15.76	0.54	0.72	0.40	9.54	1.64	146.59	4.24	137.04	4.49	156.12	4.61
60	15.92	0.41	0.78	0.47	8.29	1.70	147.56	4.30	139.26	4.71	155.85	4.52
68	15.82	0.32	0.73	0.48	6.14	1.97	148.03	4.58	141.87	5.03	154.18	4.98
76	15.60	0.33	0.59	0.44	3.33	1.86	147.65	4.54	144.33	5.01	150.97	4.81
84	15.77	0.29	0.34	0.23	0.41	1.75	146.20	4.76	146.61	5.27	145.79	4.87

TIDAL CONSTITUENT: K1

12	21.60	0.37	-0.10	0.52	7.47	1.61	168.39	3.93	160.91	5.12	175.87	3.15
20	23.22	0.51	-0.36	0.55	3.72	1.47	168.19	4.03	164.45	4.77	171.92	3.72
28	27.22	0.53	-1.26	0.45	2.67	0.94	166.73	4.15	164.06	4.65	169.41	3.81
36	30.75	0.52	-1.76	0.44	1.71	0.60	165.69	4.49	163.98	4.70	167.40	4.34
44	33.20	0.47	-1.79	0.55	1.09	0.54	164.51	4.38	163.41	4.42	165.58	4.40
52	34.06	0.44	-1.79	0.42	0.93	0.51	163.86	4.53	162.95	4.71	164.78	4.42
60	34.22	0.40	-1.51	0.35	0.82	0.61	163.84	4.53	163.05	4.66	164.66	4.50
68	34.07	0.35	-1.50	0.29	0.35	0.61	164.05	4.58	163.71	4.71	164.41	4.51
76	33.70	0.36	-1.65	0.26	-0.45	0.55	163.87	4.59	164.30	4.66	163.42	4.58
84	32.93	0.38	-1.76	0.25	-1.59	0.51	164.21	4.64	165.81	4.67	162.61	4.69

TIDAL CONSTITIUENT: N2

12	13.96	0.74	2.09	0.35	16.27	1.28	153.82	9.22	137.55	9.40	170.09	9.21
20	14.68	0.69	2.03	0.45	11.48	1.42	152.47	8.94	141.00	8.91	163.94	9.18
28	16.46	0.54	1.48	0.43	8.02	1.44	150.70	9.07	142.70	9.00	158.71	9.37
36	18.43	0.49	1.23	0.33	7.38	0.96	150.59	8.93	143.22	8.98	157.96	8.95
44	19.01	0.46	1.09	0.44	7.33	1.35	149.67	8.60	142.34	8.71	156.99	8.68
52	19.20	0.40	0.76	0.39	6.60	0.98	148.71	8.27	142.11	8.41	155.29	8.20
60	19.12	0.36	0.54	0.39	6.36	0.89	148.47	8.29	142.09	8.32	154.81	8.37
68	18.73	0.39	0.16	0.35	5.39	0.86	148.25	8.38	142.85	8.43	153.66	8.37
76	18.27	0.45	-0.23	0.30	4.55	1.12	147.82	8.19	143.27	8.47	152.41	8.06
84	17.77	0.39	-0.49	0.31	3.35	1.15	147.78	8.12	144.42	8.50	151.11	7.92

TIDAL CONSTITUENT: M2

12	81.39	0.59	-1.70	0.33	182.05	0.73	351.26	8.89	169.21	9.17	173.31	8.63
20	88.66	0.62	-1.46	0.33	179.26	0.26	351.57	8.87	172.31	8.88	170.83	8.87
28	98.28	0.57	-0.48	0.40	179.19	0.20	352.30	8.87	173.10	8.89	171.47	8.86
36	106.45	0.47	0.29	0.35	178.89	0.21	352.93	8.92	174.03	8.96	171.82	8.89
44	112.47	0.40	0.81	0.44	178.81	0.29	353.30	8.62	174.47	8.69	172.09	8.56
52	114.46	0.40	0.84	0.37	178.91	0.28	353.50	8.63	174.54	8.74	172.40	8.57
60	114.46	0.26	0.31	0.25	179.15	0.30	353.50	8.63	174.38	8.69	172.65	8.59
68	113.34	0.25	-1.14	0.29	179.41	0.30	353.31	8.65	173.90	8.70	172.70	8.60
76	111.58	0.25	-2.89	0.27	179.57	0.26	352.93	8.65	173.36	8.69	172.48	8.63
84	108.78	0.36	-4.19	0.28	179.69	0.20	352.79	8.68	173.10	8.71	172.46	8.65

TIDAL CONSTITUENT: S2

12	16.74	0.63	0.57	0.37	-2.25	1.61	180.11	9.92	182.35	10.07	177.87	10.00
20	18.33	0.55	0.58	0.40	-6.04	1.62	180.13	9.97	185.67	9.58	173.58	10.26
28	20.89	0.63	-0.07	0.49	-6.04	1.55	178.64	9.15	184.65	9.06	172.62	9.48
36	22.34	0.74	-0.72	0.47	-6.61	1.45	177.92	9.18	184.53	9.05	171.31	9.54
44	23.71	0.51	-1.29	0.48	-6.92	1.48	178.60	9.42	185.51	8.87	171.68	10.19
52	24.00	0.37	-1.56	0.48	-6.72	1.44	178.86	9.58	185.61	9.50	172.08	9.92
60	23.72	0.36	-1.81	0.56	-7.06	1.43	179.24	9.31	186.32	9.36	172.15	9.47
68	23.55	0.34	-1.91	0.58	-7.11	1.41	179.34	8.86	186.44	8.93	172.22	9.03
76	23.41	0.29	-1.80	0.63	-6.71	1.16	179.81	8.67	186.52	8.67	173.12	8.82
84	23.44	0.26	-1.14	0.73	-6.22	1.04	181.40	8.45	187.59	8.45	175.17	8.55

TIDAL CONSTITUENT: MK3

12	12.72	0.53	-1.64	0.47	173.68	1.79	174.78	13.89	-1.12	13.47	-11.54	14.53
20	13.69	0.59	-1.91	0.58	172.52	1.30	172.55	14.20	-0.03	13.65	-14.94	14.83
28	12.56	0.48	-1.71	0.68	165.05	1.70	176.26	14.26	11.23	13.95	-18.69	14.77
36	11.51	0.45	-0.90	0.67	158.31	1.92	182.68	13.53	24.38	13.03	-19.00	14.27
44	10.87	0.40	-0.31	0.75	156.88	3.52	187.08	13.33	30.19	11.77	-16.04	15.55
52	10.80	0.42	0.08	0.66	157.04	2.69	187.03	13.22	29.98	12.04	-15.94	14.81
60	10.73	0.36	0.20	0.59	162.24	3.11	185.91	12.77	23.65	11.82	-11.83	14.32
68	10.68	0.40	0.23	0.46	169.45	2.71	184.60	12.37	15.18	11.71	-5.93	13.55
76	10.72	0.45	0.09	0.37	178.23	2.60	183.61	12.02	5.86	11.10	1.82	12.90
84	10.51	0.46	-0.73	0.35	185.96	2.84	177.38	11.67	-8.30	11.49	3.34	12.74

TIDAL CONSTITUENT: M4

12	13.71	0.50	-0.32	0.66	171.54	2.21	179.48	17.27	7.43	18.91	-8.97	15.84
20	15.26	0.50	-1.13	0.69	172.99	1.76	177.04	17.39	4.06	18.63	-9.97	16.21
28	14.52	0.61	2.16	0.52	170.94	2.17	174.69	17.53	3.76	18.83	-14.37	16.40
36	12.64	0.45	-2.24	0.46	169.08	2.91	174.64	18.18	5.53	20.01	-16.26	16.66
44	11.08	0.44	-1.66	0.44	168.95	3.36	174.58	17.45	5.63	19.61	-16.46	15.71
52	10.31	0.46	-1.00	0.48	171.43	3.29	173.06	17.17	1.61	18.82	-15.51	16.06
60	9.86	0.44	0.06	0.44	174.72	2.65	172.47	16.83	-2.26	17.96	-12.80	16.07
68	9.55	0.42	1.31	0.40	179.66	2.72	174.88	16.60	-4.77	17.18	-5.46	16.45
76	9.42	0.49	2.66	0.34	189.15	3.59	182.95	17.06	-6.21	16.84	12.10	17.98
84	9.88	0.49	3.32	0.33	202.44	3.97	185.30	17.96	-7.15	16.48	37.73	20.14

TIDAL CONSTITUENT: 2MK5

12	5.82	0.66	-3.11	0.55	96.06	8.55	151.66	26.04	55.60	32.20	247.71	21.59
20	6.16	0.68	-2.96	0.61	103.33	7.60	144.28	26.22	40.95	32.12	247.60	21.40
28	6.07	0.46	-1.02	0.66	99.23	4.65	136.24	23.92	37.00	26.48	235.47	22.04
36	5.84	0.42	0.99	0.61	86.67	3.63	129.16	24.33	42.49	25.06	215.83	24.15
44	5.81	0.43	2.29	0.52	64.64	5.90	113.98	29.87	43.34	26.93	178.62	33.59
52	5.83	0.39	2.12	0.35	43.67	3.62	96.68	26.78	53.02	25.35	140.37	28.59
60	5.54	0.40	1.33	0.46	24.89	3.30	85.38	26.28	60.50	26.30	110.28	26.62
68	4.98	0.32	0.23	0.49	7.65	4.95	81.50	24.39	73.90	25.84	89.09	23.95
76	4.67	0.41	-0.77	0.43	161.87	4.16	87.44	24.24	105.58	26.15	69.29	22.93
84	5.26	0.51	-0.69	0.38	137.58	2.85	95.24	23.34	137.66	24.43	52.83	22.55

TIDAL CONSTITUENT: M6

12	6.70	0.38	0.03	0.50	108.98	4.59	226.63	26.74	117.65	28.10	-24.37	26.14
20	7.13	0.39	0.34	0.55	114.64	4.56	228.42	27.21	113.78	28.14	-16.93	27.02
28	6.36	0.39	0.99	0.54	120.63	4.26	233.62	28.94	113.00	29.74	-5.76	28.76
36	5.64	0.43	1.25	0.42	127.09	5.14	240.55	28.55	113.46	28.45	7.64	29.53
44	5.06	0.63	1.31	0.36	137.35	8.77	247.94	28.75	110.57	30.41	25.30	29.67
52	4.32	0.24	1.13	0.35	152.71	8.86	255.60	29.42	102.90	29.92	48.30	31.51
60	3.94	0.33	0.72	0.46	175.32	7.72	263.15	28.92	87.84	29.60	78.47	30.29
68	4.00	0.45	0.06	0.40	194.07	4.60	265.73	28.83	71.64	28.95	99.80	29.44
76	4.22	0.42	-0.62	0.36	211.27	3.96	264.39	28.65	53.11	28.55	115.65	29.31
84	4.51	0.28	-0.91	0.38	227.12	4.82	260.59	29.21	87.47	14.88	127.71	29.71

TIDAL CONSTITUENT: 3MK7

12	7.16	0.39	-1.19	0.35	119.15	3.05	28.60	31.43	269.13	30.55	147.46	33.30
20	7.72	0.37	-1.14	0.41	125.44	3.13	29.70	32.99	264.25	32.01	155.13	34.25
28	7.10	0.38	-1.01	0.40	122.37	5.08	36.82	31.90	274.44	28.70	159.20	35.57
36	6.20	0.42	-0.76	0.33	112.10	6.87	44.91	32.03	292.83	28.97	157.01	36.16
44	5.07	0.56	-0.29	0.31	101.14	7.94	48.91	28.39	307.74	24.16	150.03	33.97
52	3.69	0.50	-0.06	0.28	97.87	9.64	51.49	29.57	295.62	67.70	149.34	34.79
60	1.60	0.43	0.25	0.28	109.40	23.60	53.46	28.96	286.04	64.49	162.84	42.65
68	1.37	0.52	-0.24	0.23	59.42	26.62	91.71	43.65	176.28	62.73	286.14	38.77
76	3.76	0.45	-0.51	0.41	71.25	5.89	46.31	33.67	155.06	36.98	297.55	31.14
84	5.94	0.41	-0.63	0.47	77.68	3.12	43.33	32.03	145.66	33.22	301.02	31.13

M2 inclination, Figure 13c, was consistent about 179° through the depth of the record. The phase shift from Greenwich was fairly constant with depth, 352° , Figure 13d.

b. Primary Constituents

The remaining primary constituents, O1,K1,S2, and N2, were of the same order of magnitude, ranging from about 30 cm/s for K1 to 10 cm/s for O1. In all four of the primary constituents the semi-major axis increases monotomically from 12m to a maximum at 60 to 68 meters depth (Figure 14a). Below 68 meters depth the semi-major axis decreases slightly with depth. The primary constituents demonstrated little cross channel flow, Figure 14b. The O1 and N2 constituents had similar semi-minor axis profiles with maximums near the surface going to near zero by 84 meters, Figure 14b. The K1 and S2 started at close to zero near the surface and reached maximums of about 2 cm/s between 68 and 80 meters, Figure 14b. Primary constituent inclination and phase shift profiles were similar, Figures 14c and 14d. The inclinations all had maximums near the surface that decreased with depth. All had phase shifts to Greenwich that were nearly constant with depth.

c. Overtide Constituents

The strongest of the secondary constituents was the M4 overtide, Figure 15. The M4 semi-major axis was 15.3 cm/s at 20 meters, Figure 15a. The semi-major axis then decreased with depth to a minimum of 9.4 cm/s at 76 meters depth. The M6 semi-major axis demonstrated a similar profile to the M4, Figure 15a. Semi-major axis 7.1 cm/s, occurred at 20 meters. It then decreased to a minimum amplitude of 3.9 cm/s at 60 meters depth. M6 semi-minor axis was not statistically greater than zero until deep in the water column, below 76 meters, where it was about 3 cm/s, Figure 15b. Inclination of the M4 ellipse was fairly consistent averaging about 171° through depth, Figure 15c. M6 inclination increased with depth from 109° near the surface to 227° at 84 meters depth, Figure 15c. Phase shift from Greenwich was moderate for both M4 and M6. M4 was fairly constant with an average G of 175° . M6 increased from 226° at 12 meters to 255° at 52 meters.

d. Compound Constituents

MK3 had greatest semi-major axis of the compound constituents with a maximum of 13.7 cm/s at 20 meters, Figure 16a. 3MK7 and 2MK5 also had semi-major axis maximums at 20 meters, 7.7 cm/s and 6.2 cm/s respectively. Below 20 meters the profiles are no longer similar. MK3 decreased with depth to 44 meters below which it maintained a near constant average of 10.7 cm/s. 2MK5 varied between 5.8 cm/s and 4.7 cm/s from 20 to 84 meters. 3MK7 decreased rapidly to 1.4 cm/s at 68 meters, then increased to 5.9 cm/s at 84 meters. All three compound tides semi-minor axis were significantly greater than zero only in the upper 20 meters at 1 to 2 cm/s with a clockwise rotation, Figure 16b. Inclination was also inconsistent between the three compound constituents, Figure 16c. MK3 inclination decreased from a 12 meter maximum of 173.7° to a mid-layer minimum of 156.9° at 44 meters. MK3 inclination then increased to 169.5° at 68 meters before dropping off rapidly with depth. 3MK7 and 2MK5 had near surface maximum inclinations at 20 meters of 125.4° and 103.3° respectively. Both then decrease with depth. The 2MK5 reached a minimum of 24.9° at 60 meters, increased to 161.9° at 76 meters then decreased again to 137.6° at 84 meters. The 3MK7 minimum of 59.4° at 68 meters was not statistically significant. Unlike the 2MK5, the 3MK7 reached a statistically significant minimum at 76 meters, 71.3°, then increased slightly to 77.7° at 84 meters.

e. Summary

The period from 0200Z, 20 November, 1992 to 0300Z, 21 November, 1992 was chosen to represent a typical tidal day for descriptive analysis. The Foreman predicted tidal along channel and cross channel tidal currents were plotted in Figure 17. The along channel currents clearly demonstrated the depth dependency of the flood tide, positive along channel flow, and the associated shear. Cross channel flow contours were extremely noisy. There was also observed southward flow from the surface to mid depth toward the end of the second daily flood. A pattern of midlevel maximums prior to maximum ebb occurred. Note that this agrees with the pattern of the scatter diagrams, Figure 12.

5. Low Frequency (Subtidal) Analysis

Low frequency physical processes were complex and difficult to isolate. Low frequency events can only be accurately isolated in linear systems (Conomos and Gartner, 1985). The complex topography of Golden Gate combined with the large tidal prism makes this a very nonlinear system. Therefore, a qualitative approach was used for the analysis of subtidal processes.

To examine the subtidal residual currents, the results of the Foreman tidal analysis were subtracted from the rotated, demeaned signal to yield a detided signal. The detided signal was then filtered using a 72 hour Butterworth lowpass filter. Detailed detiding and low frequency analysis procedures are discussed in Appendix D. Data from the near bottom CTD, Fort Point surface measurements, winds on Golden Gate bridge, NAS Alameda, and NOAA tide gauges were low passed using a 72 hour Butterworth filter. The results were then compared using various combinations of stack plots and covariance functions.

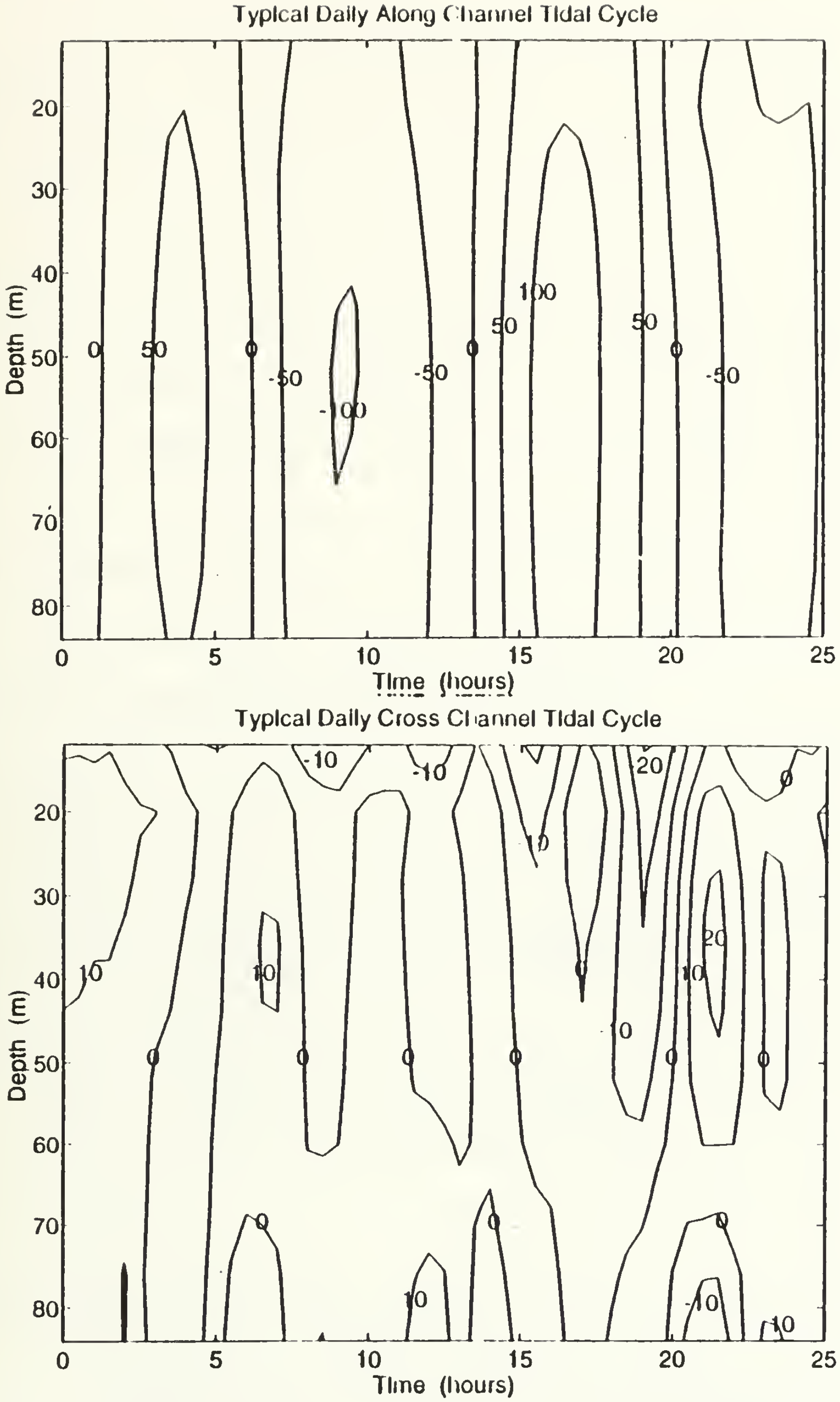


Figure 17. Typical Daily Tidal Cycle for the Golden Gate.
a. Along Channel Flow
b. Cross Channel Flow

The along channel current variations were consistent with depth and showed a large amplitude event on about 5 December, Figure 18. The cross channel currents, Figures 19, reversed with depth. The upper layer, 12 meters, tending to the north, and the bottom layers, 60 to 84 meters, tending to the south, Figure 19. The crossover occurred around 36 meters depth which showed near zero but slightly south current, Figure 19. The vertical average of the cross channel residual currents was northward, about 2.0 cm/s.

Next, moored CTD data was compared to the low passed currents, Figure 20. Moored CTD data was detided using a 72 hour Butterworth low pass filter. In Figure 20 the CTD temperature and salinity data was detrended, which removed the cooling (0.11 ° C/day) and freshening (0.09 psu/day) observed, Figure 4, but retained other subtidal variability. The moored CTD salinity showed consistent freshening through the record until 5 December. On 5 December the freshening trend reversed for about five days and resumed on about 10 December. The CTD temperature cooling trend was slow during the first ten days. From 21 November to 30 November the cooling trend was consistently strong. The cooling trend weakened from 01 December until interrupted and reversed on about 10 December. The cooling trend seemed to reestablish around 12 December.

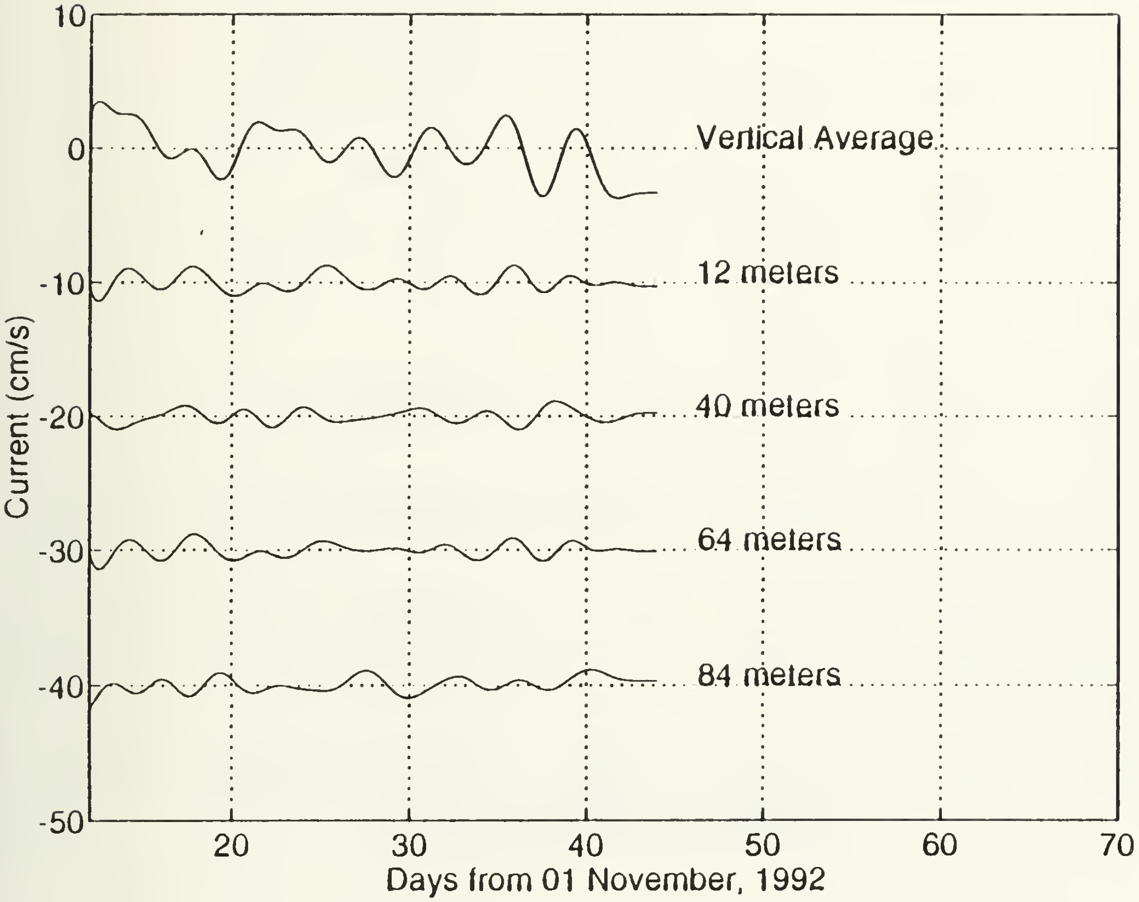


Figure 18. Subtidal Along Channel flow in the Golden Gate. The vertical average has been subtracted from individual levels, and results have been displaced by increments of 10 cm/s for clarity.

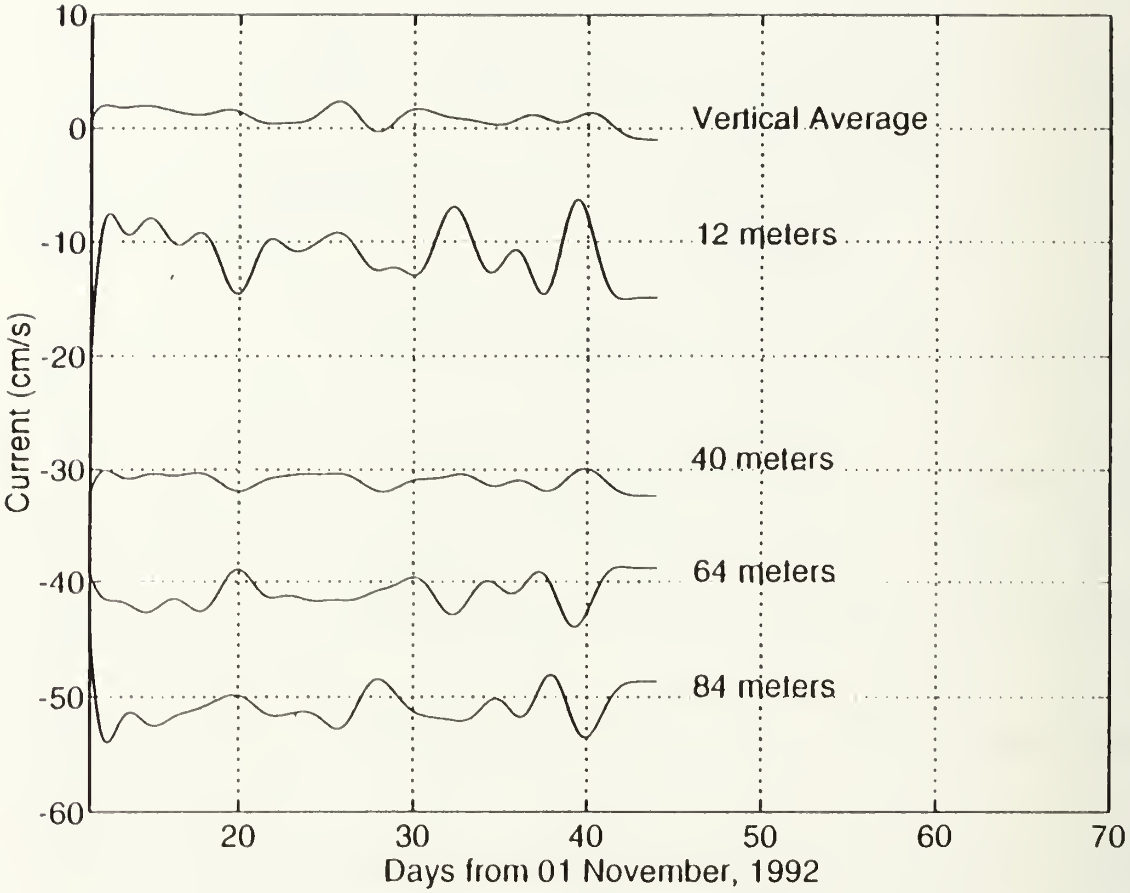


Figure 19. Subtidal Cross Channel flow in the Golden Gate. The vertical average has been subtracted from individual levels and results have been displaced by increments of 10 cm/s for clarity.

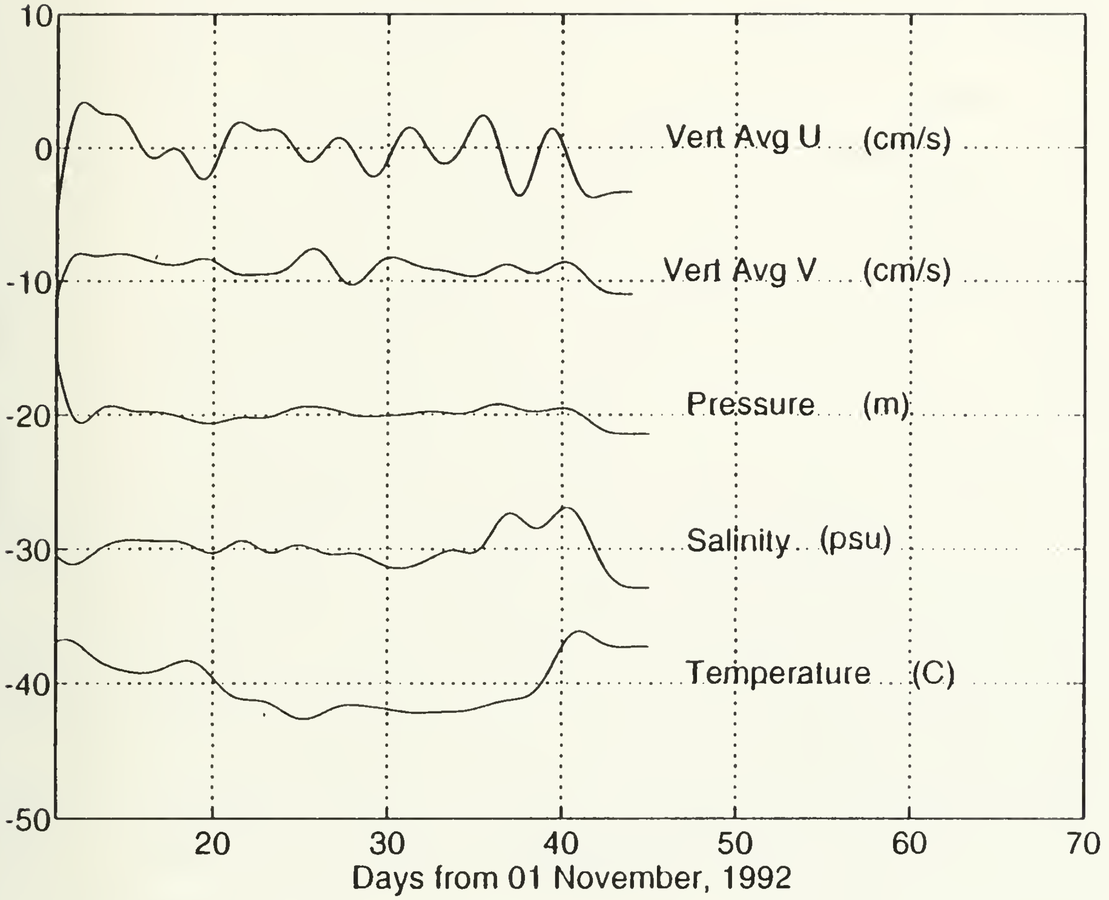


Figure 20. Residual CTD Pressure, Salinity, and Temperature with Vertically Averaged Residual Along and Cross Channel Currents for the Golden Gate.

The subtidal CTD pressure, salinity, and temperature were cross correlated to the subtidal U and V current components, Figures 21 and 22. Salinity was positively correlated to the along channel (U) component with lead of about a day, Figure 21. This indicated that salinity and pressure increased with flow into the Bay. Salinity also had a negative correlation with a 36 hour lag. Temperature was not well correlated with the U component. As expected, pressure was positively correlated to along channel flow. (The "notch" in this correlation function at zero lag is unusual, a feature for which I have no explanation) Figure 22 showed subtidal salinity and pressure positively correlated with the residual cross channel flow.

Low passed winds were compared to subtidal current components in Figure 23. Persistent southeastward winds were observed. During the first six days of the record, 11 through 17 November, the Gate experienced southeastward winds of varying strength. During this period the vertically averaged along channel current was into the Bay, opposite to the Ekman transport. When the southeastward wind relaxed, the along channel currents resumed an oscillation about zero. In Figure 24 the along channel currents were negatively correlated with a lag of almost 4 days.

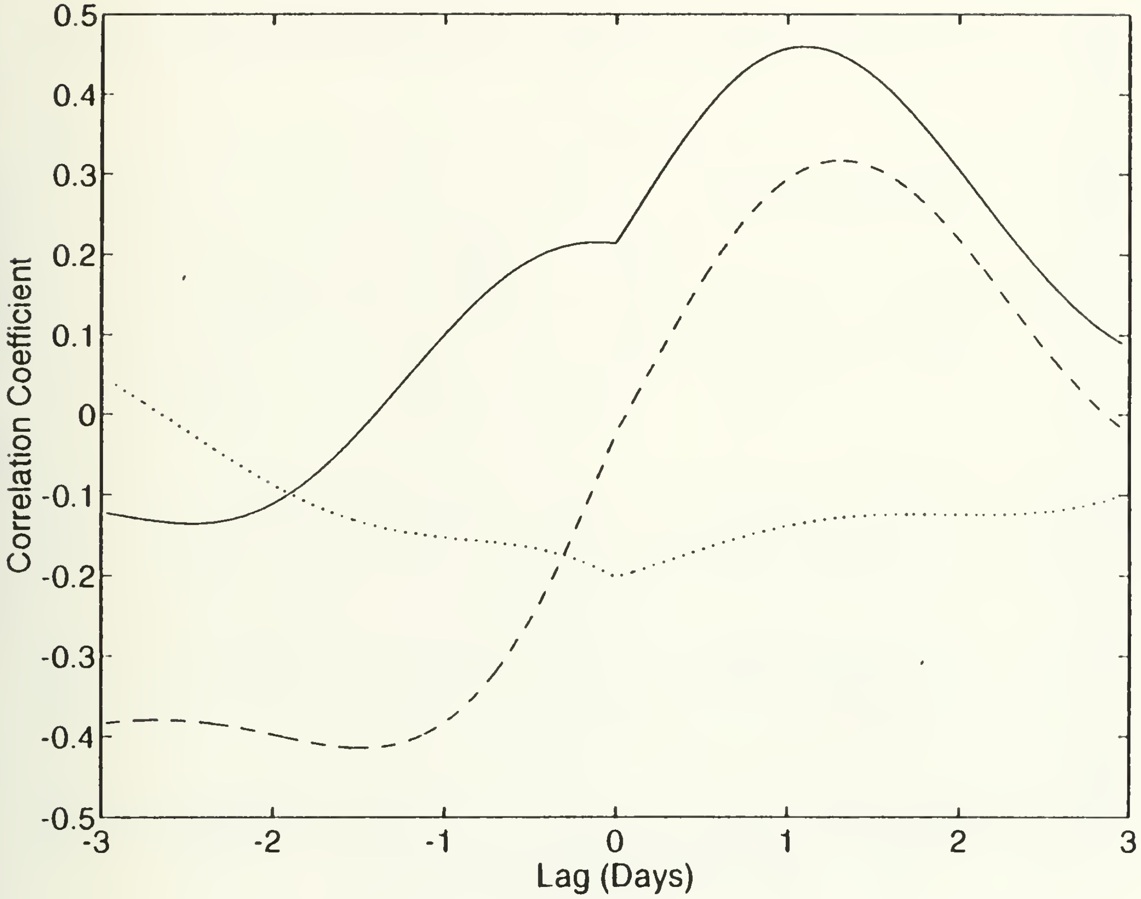


Figure 21. Cross Correlation of Low Passed Near Bottom CTD Data with Vertically Averaged Residual Along Channel Current in the Golden Gate. Solid line is pressure. Dashed line is salinity. Dotted line is temperature.

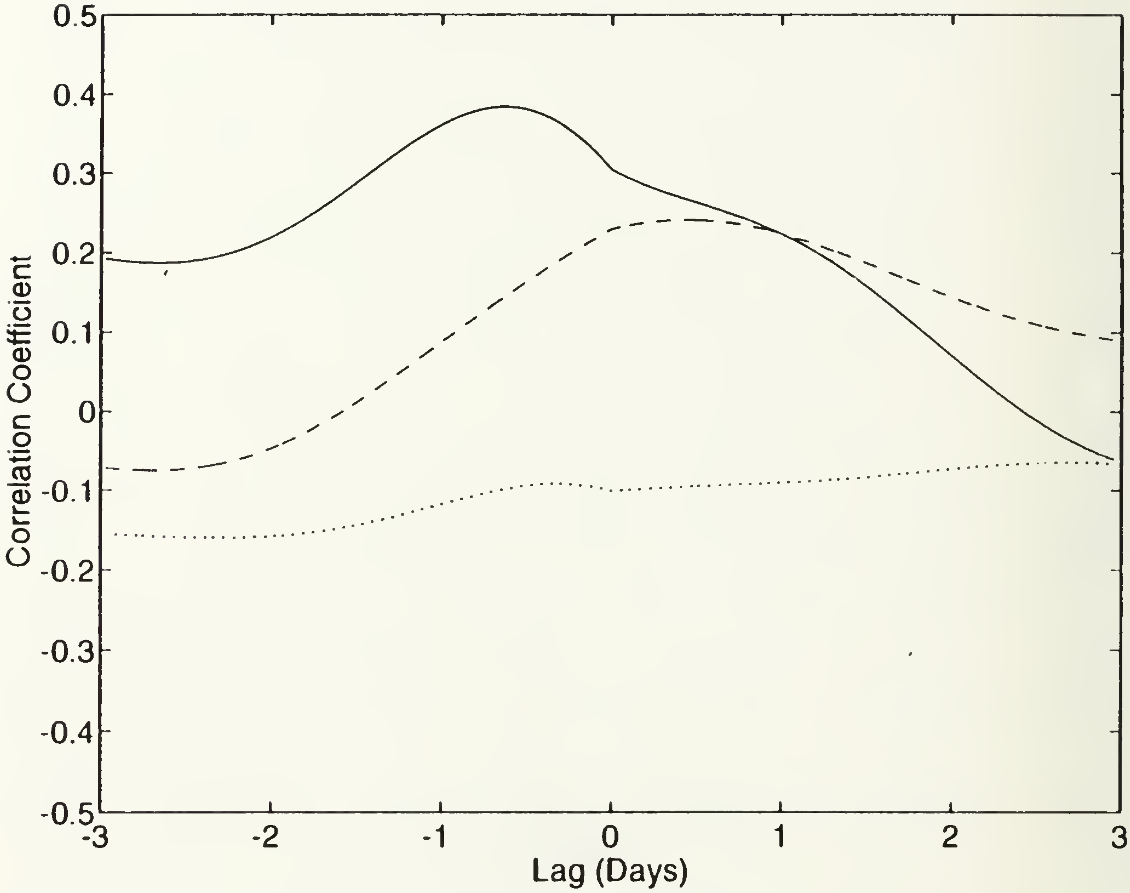


Figure 22. Cross Correlation of Low Passed Near Bottom CTD Data with Vertically Averaged Residual Cross Channel Current in the Golden Gate. Solid line is pressure. Dashed line is salinity. Dotted line is temperature.

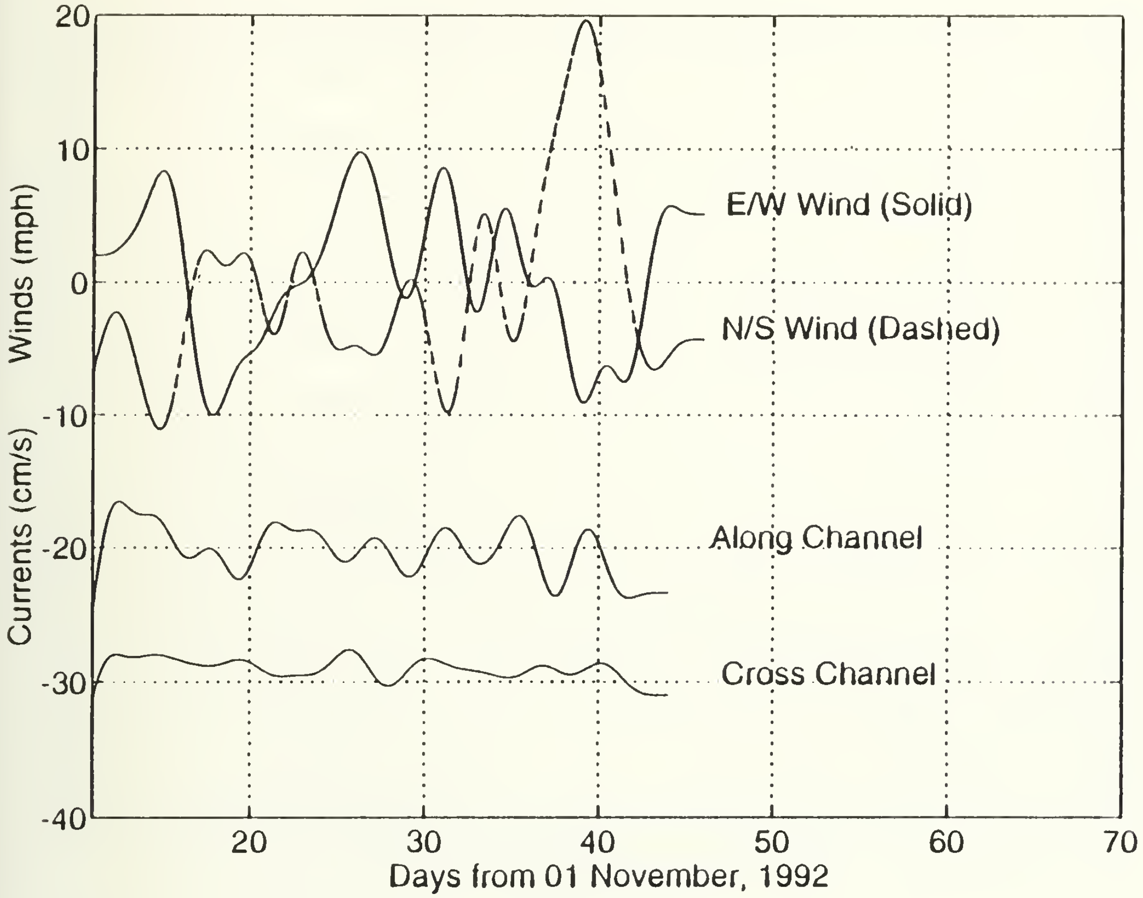


Figure 23. Low Passed Winds with Vertically Averaged Residual Along and Cross Channel Currents in the Golden Gate.

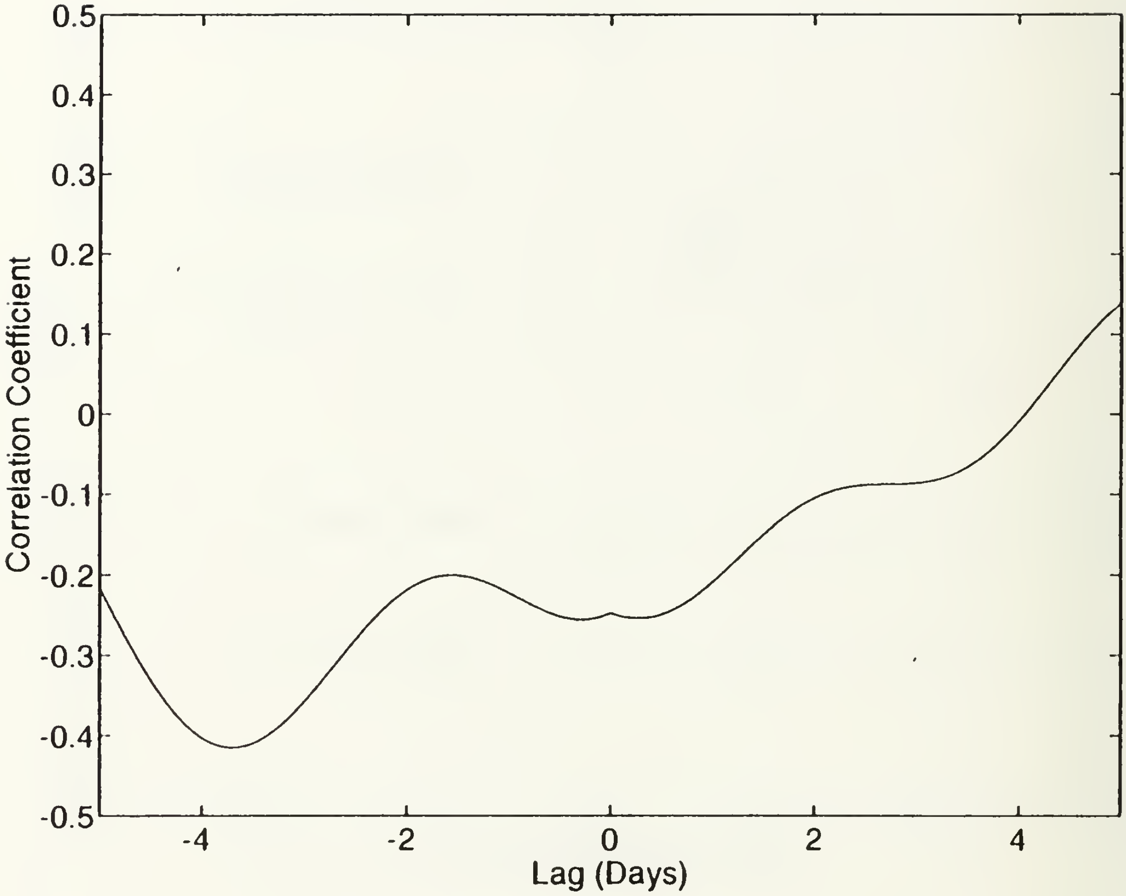


Figure 24. Cross Correlation of Residual Along Channel flow with North/South Winds in the Golden Gate.

Along channel currents had a positive correlation with lag of 12 hours, Figure 25, i.e. the direction of flow is opposite to the wind stress. This result may be associated with the correlation between southward and eastward winds. Finally, from Figure 26 no correlation was found to exist between E/W winds and the cross channel current.

A second meteorological influence was a series of storms in early December. Two short but fairly intense events occurred on 02 December and 06 December. A less intense but longer duration rain event occurred from 08 through 11 December, 1992. The two short intense storms had strong southeastward winds that appeared to strengthen flow into the bay. During the 08 through 11 December period, a southeastward wind gave way to strong sustained northwestward winds. The combined effect of these storms appeared to enhance flow out of the bay. The disturbance to along channel flow from these storms was clearly evident through the entire depth of the along and cross channel currents, Figures 18 and 19.

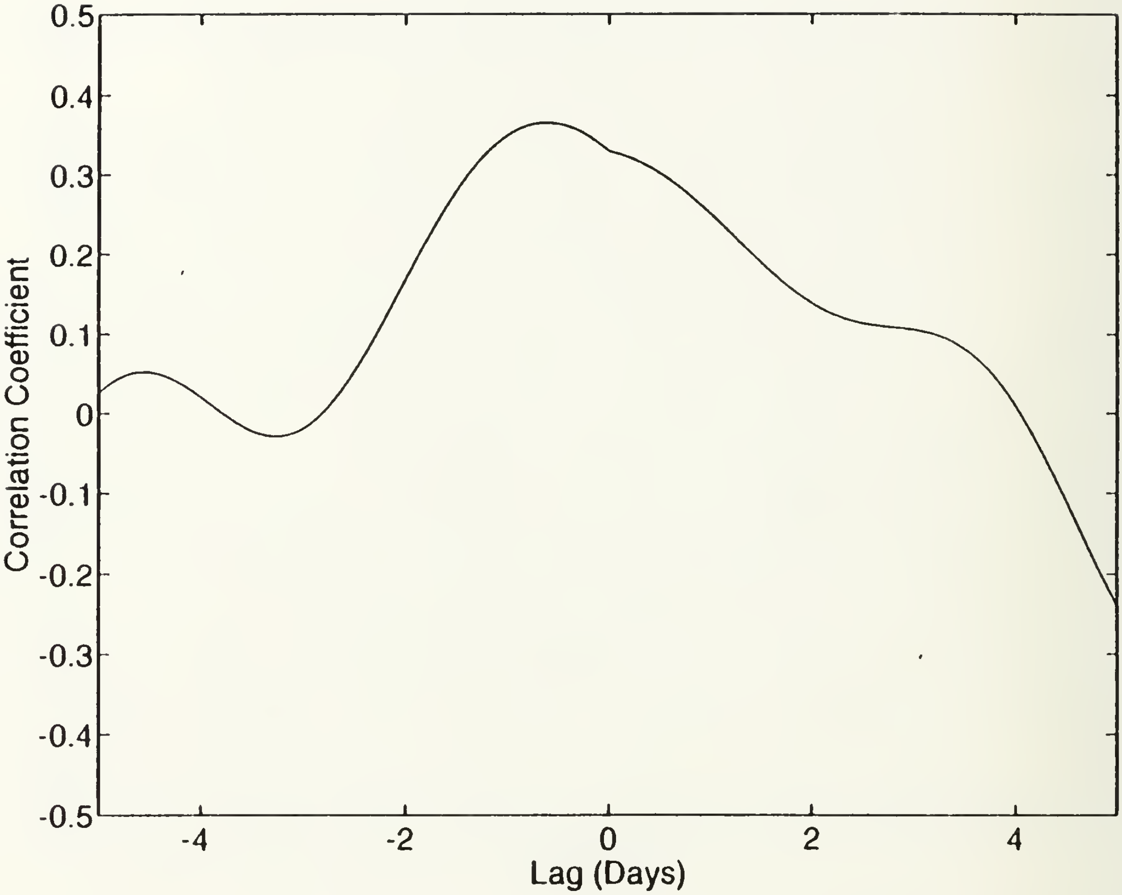


Figure 25. Cross Correlation of Residual Along Channel Current with East/West Winds in the Golden Gate.

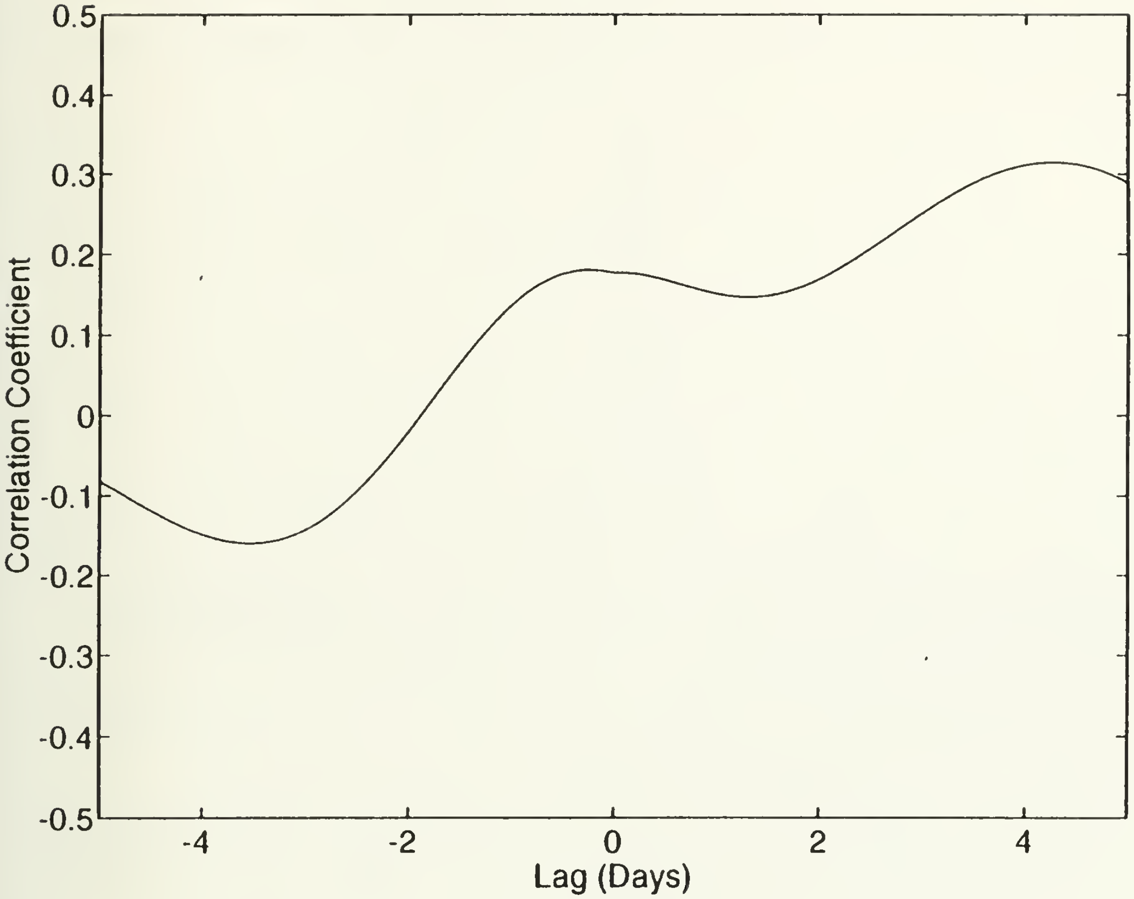


Figure 26. Cross Correlation of Residual Cross Channel Current with East/West Winds in the Golden Gate.

6. High Frequency Analysis

Analysis of the detided data was essential, both to see how successful the least squares technique had been as well as attempting to isolate higher frequencies to the tidal driving force. The high frequency response revealed the existence two interesting signals. One with a period of 5 hours the other a period of 1.67 hours.

The unbiased along channel covariance indicated a 4 to 6 hour response that changes phase from positive at the surface to negative in the bottom 16 meters of the water column, Figure 27. A spectral analysis of the covariance revealed a consistent spike at 5 hours, Figures 28. The 2MK5 tide has about a 5 hour period. Extremely little temporal distortion of the along channel internal wave was demonstrated by the nearly point "zero" crossings of the nine covariances. The spectral analysis of the along channel high frequency information also revealed a consistent signal with a 1.67 hour period. This signal was not easily seen in the covariance but was clearly revealed by the "fast fourier transform" of the high frequency signal through all depths.

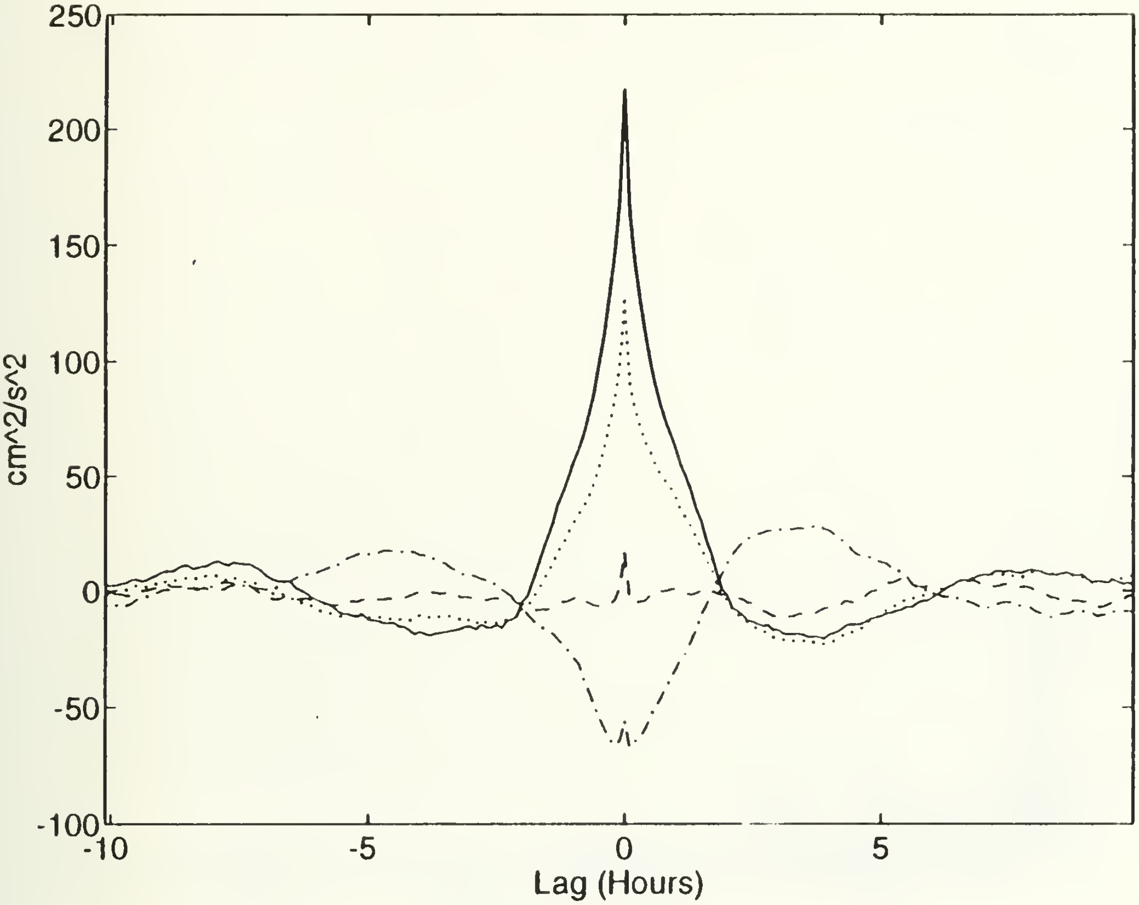


Figure 27. Covariance of Along Channel High Frequency Currents in the Golden Gate. Solid line is 12 - 20 meters. Dotted line is 12 - 40 meters. Dashed line is 12 - 64 meters. Dashed-Dotted line is 12 - 84 meters.

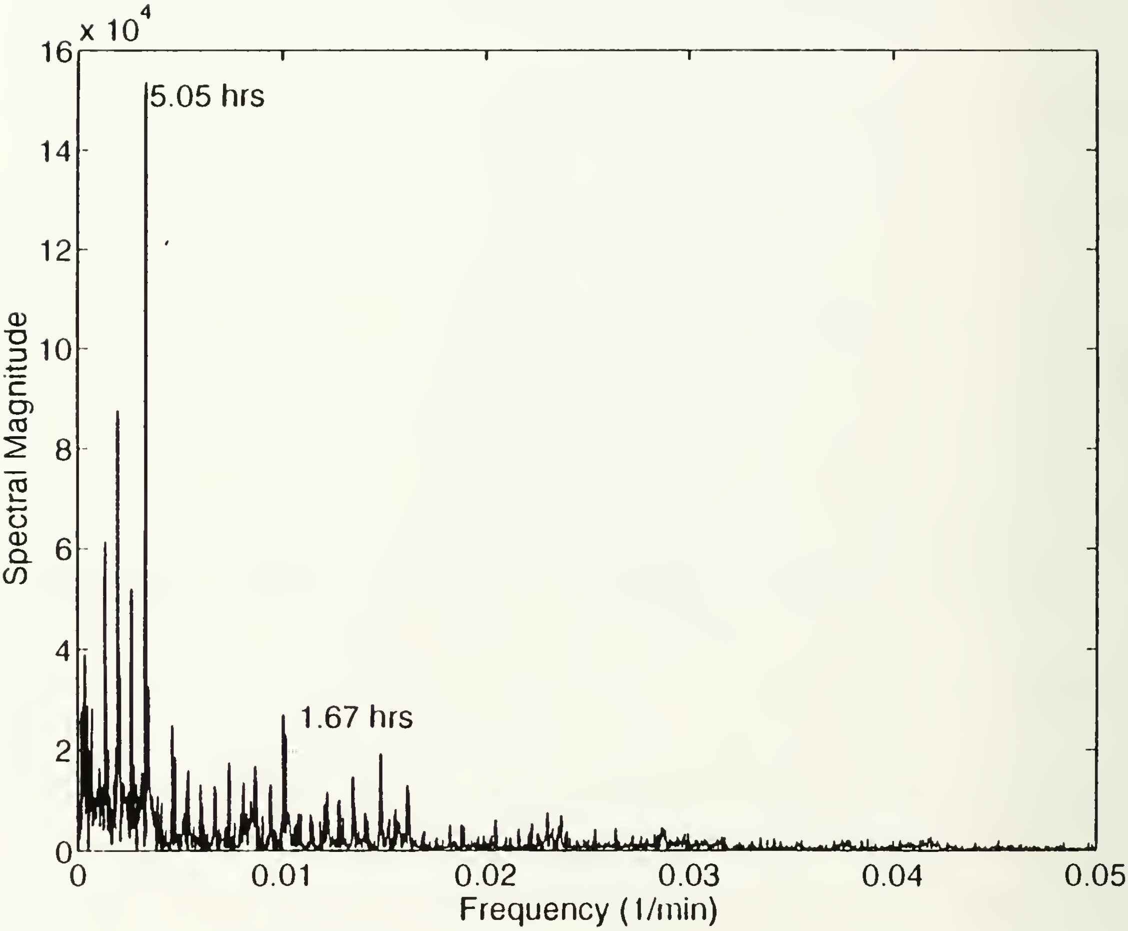


Figure 28. Spectral Analysis of Along Channel Covariance, Currents at 12 meters to currents at 20 meters depth in the Golden Gate.

Cross channel covariances, Figure 29, demonstrated a similar depth dependant phase shift as the along channel. A cross channel wave period of order 4 to 6 hours was evident. Unlike the along channel, the cross channel covariance demonstrated temporal change with depth, Figure 29. Rotary spectral analysis was performed on the raw and detided data to observe the relative significance of high frequency signals and evaluate the efficiency of the detiding effort. In Figure 30 the reduction of low frequency tidal energy is clearly evident. The 5 hour signal discussed in the high frequency analysis was not significantly reduced by the detiding effort. This 5 hour signal was present through the entire depth of the record with a clockwise rotation. The 5 hour energy may be the result of the nonstationarity of the signal. A 1.67 hour signal was also observed in the high frequency rotary spectrum (Figure 30) within the 95 percent confidence interval and with clockwise rotation.

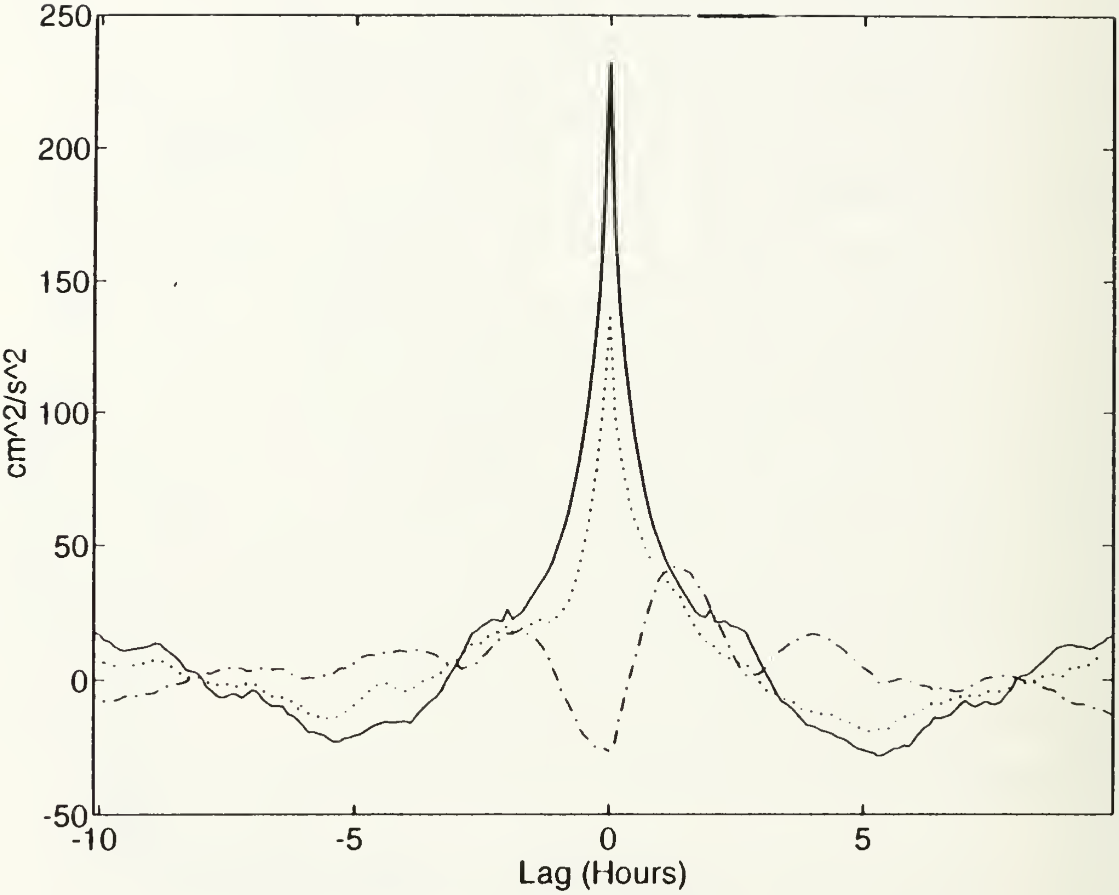


Figure 29. Covariance of Across Channel High Frequency Currents in the Golden Gate. Solid line is 12 - 20 meters. Dotted line is 12 - 40 meters. Dashed-Dotted line is 12 - 84 meters.

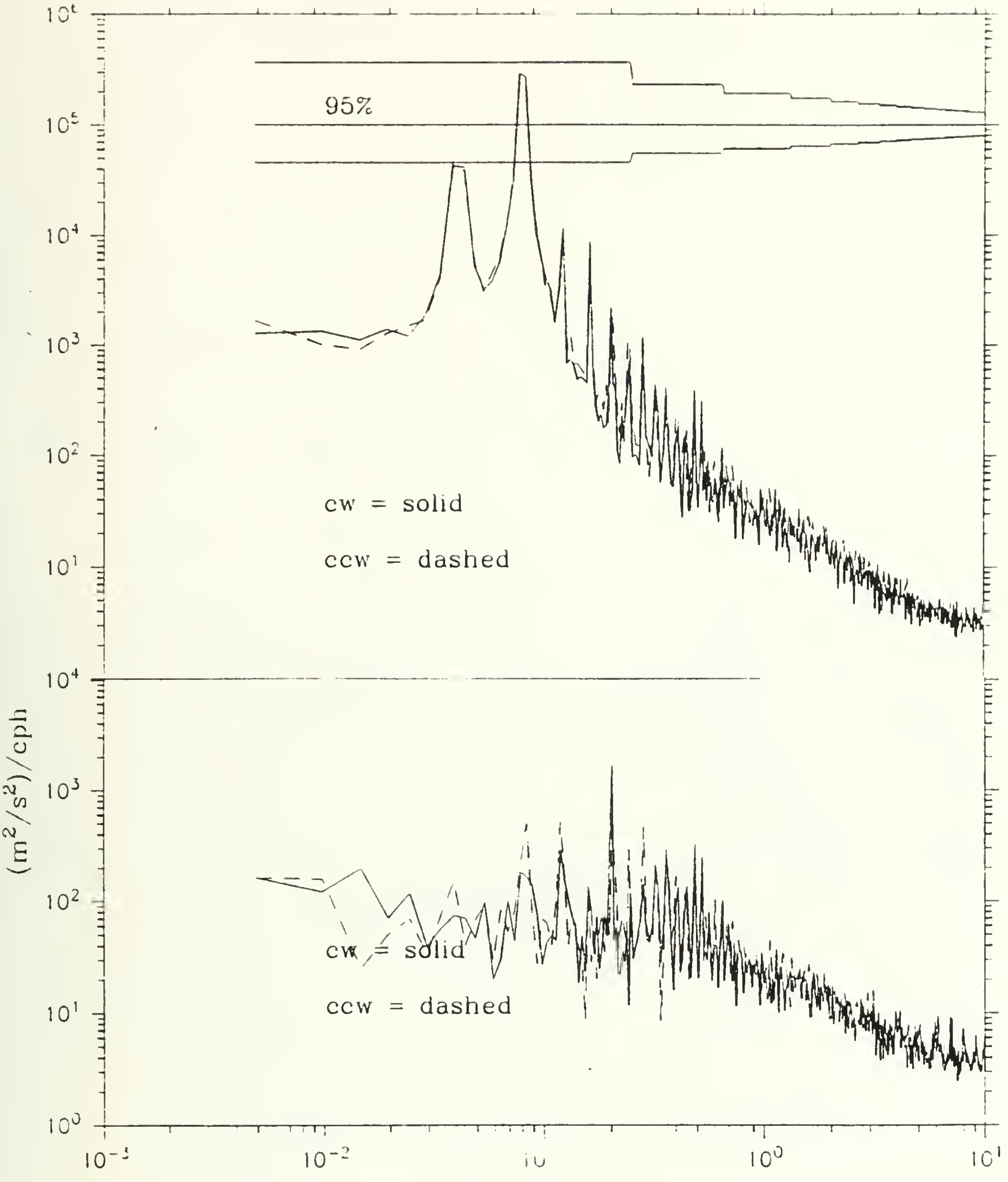


Figure 30. Rotary Spectrum of Raw and Detided Currents in the Golden Gate. Solid line is clockwise rotation. Dashed line is counterclockwise rotation.

C. COMPLEX DEMODULATION

The change in time of the amplitude and phase of the frequencies of interest previously determined was examined through complex demodulation. The frequencies of interest included: the strong M2 semi-diurnal tide at 0.0805 cph, and the major diurnal constituent, K1 at 0.0418 cph.
The pressure, temperature, and salinity signals from the moored CTD were demodulated at these frequencies.

Demodulated semidiurnal variability, Figure 31a, for temperature drops slightly during the first seven days of the deployment, has a sudden two day spike, then drops rapidly from 20 November to almost zero by 5 December. After about a day of zero amplitude the semidiurnal temperature energy starts a oscillatory increase through the remainder of the record. Salinity semidiurnal variability, Figure 31a, remained relatively constant with fortnightly beating through the record. The amplitude of semidiurnal salinity variability rose dramatically during storm events late in the record. The maximum recorded amplitude occurred around 8 December, 0.6 psu. After 8 December the amplitude decreased.

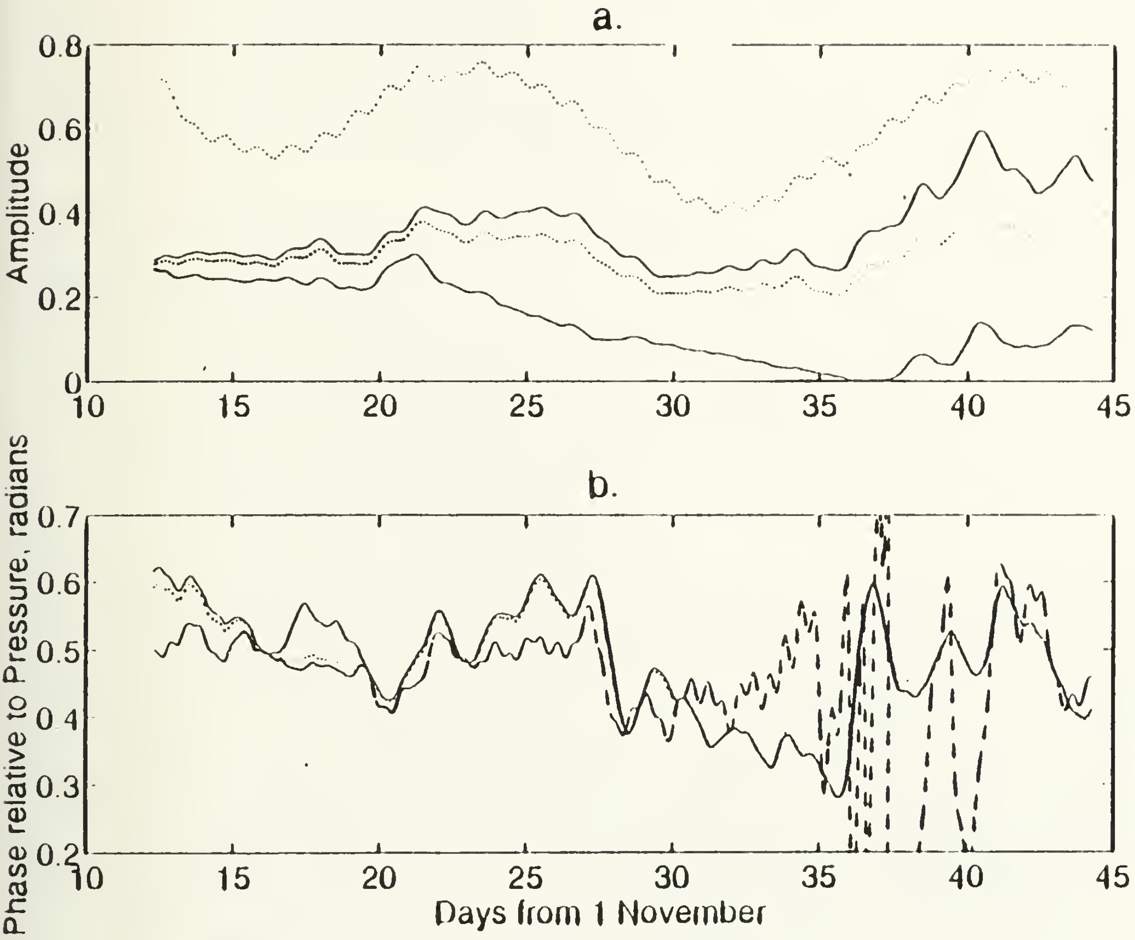


Figure 31. Demodulation of Semidiurnal Energy for Pressure, Temperature, Salinity, and Density in the Golden Gate. Dotted line is pressure. Solid line is salinity. Dashed line is temperature. Dotted line between salinity and temperature is density.

a. Amplitude.

b. Phase Relative to Pressure.

for the salinity throughout the record, Figure 31b. Temperature semidiurnal phase was also locked between 150 and 180 degrees until about 1 December when it started to drift. Starting about 6 December the temperature phase shifted wildly during the several days of storms. Around 11 December the semidiurnal temperature signal seemed to return into near phase lock with salinity.

Demodulation of the diurnal signal gave similar results to the semidiurnal. Diurnal salinity amplitude followed the fortnightly beating demonstrated by the pressure signal, Figure 32a, until the storm events late in the record. During the storm events the salinity diurnal amplitude increased markedly. Diurnal temperature energy followed the salinity pattern until 20 November when it started a steady decline to zero by 6 December. During the early December storm events some diurnal energy returned to the signal. Diurnal phase for salinity and temperature had a consistent fortnightly shift between 0.2 to 0.8 radians and lagged the pressure by about five days, Figure 32b, until the early December storms. During the storm events the diurnal salinity phase shifted dramatically to about 0.2 radians oscillating by no more than 0.1 radian for the remainder of the record. The diurnal temperature phase shifted wildly during the storm events.

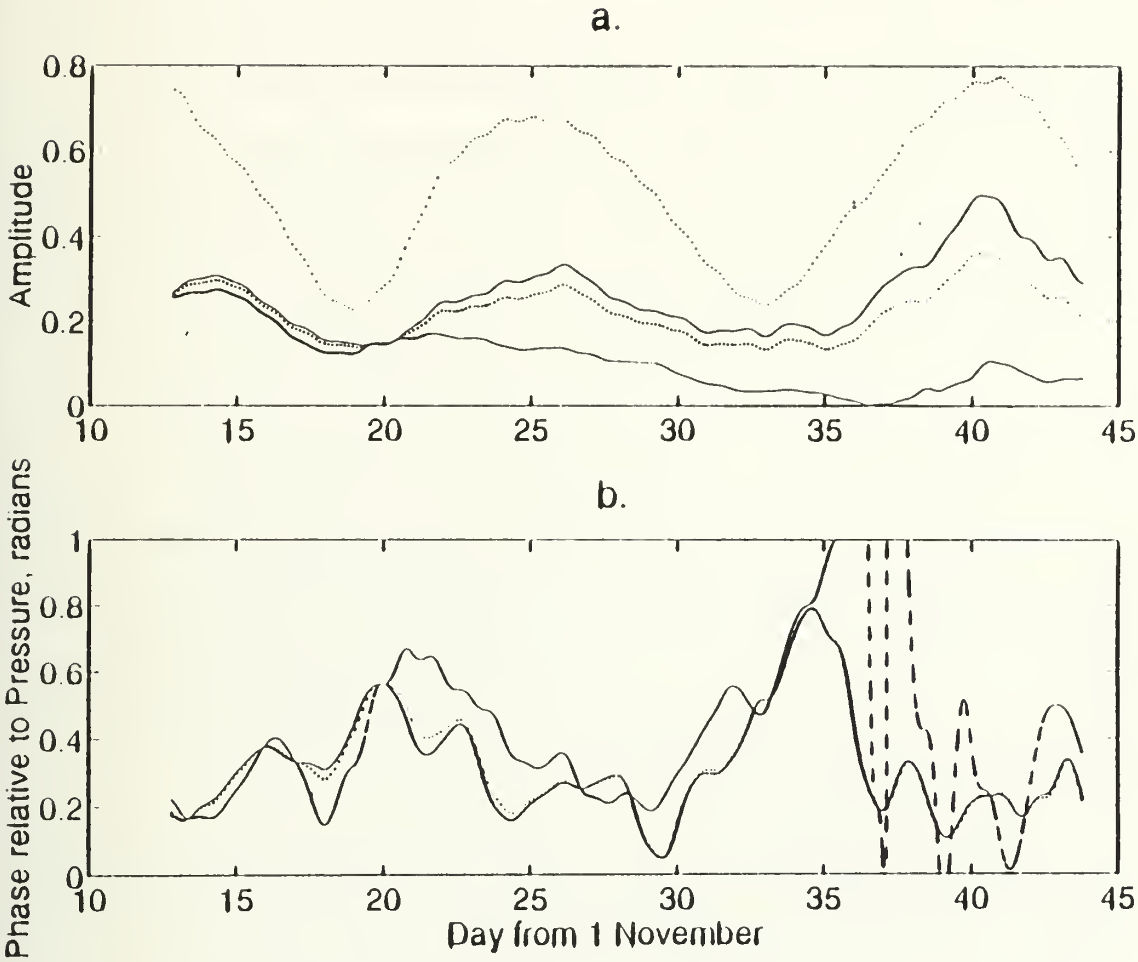


Figure 32. Demodulation of Diurnal Energy for Pressure, Temperature, Salinity, and Density in the Golden Gate. Dotted line is pressure. Solid line is salinity. Dashed line is temperature. Dotted line between salinity and temperature is density.

a. Amplitude.

b. Phase Relative to Pressure.

IV. DISCUSSION

Currents in the Golden Gate are complex and subject to strong tidal forcing. I found the mean currents measured by the current profiler to be directed into the Bay (110° T) with a speed of 26 cm/s. Mean floods were also clearly greater than the mean ebbs. This apparent flooding of the San Francisco Bay is most likely due to the two dimensional structure of the flow in the Gate and the Eulerian nature of the measurements. For example, if the distribution of the ebb and flood currents are not symmetric mirror images across the Gate, than a bias will be introduced to measurements at a fixed location. I did clearly measure a strong tidal jet associated with the flood tide. Other residual (subtidal) circulations could also contribute to this bias. Our measurements fit the structure of flow described by Conomos and Gartner (1985):

> The inflow follows the depths along the south shore of the entrance to the bay, whereas the surface outflow tends to follow the more shoal areas and is concentrated toward the northern shore. Superimposed upon this circulation pattern is a tidally driven residual flow that is directed up estuary in the center of Golden Gate, toward the ocean along the shores. (Conomos and Gartner, 1985)

This pattern of flow also agrees with theoretical and numerical analysis of Park and Wang (1991). They studied the vorticity balance of tidal flows over a hollow in a the vorticity balance of tidal flows over a hollow in a straight rotating channel (Park and Wang, 1991), a situation resembling the topography of the Golden Gate. They found a pattern of residual currents which have inflow to the south and outflow to the north.

Tidal forcing dominated the kinetic energy of the currents and changes of the potential energy of sea level. The mixed character of the tide is reflected in strong, nearly rectilinear motion associated with the primary tidal constituents. Considerable shear (20% for the M2 tide) was observed which with deep flow maximums (60 - 70 meters depth) indicate the jet-like character of the flow. Overtide and compound tides had amplitudes of about 5 cm/s, these tended to be strongest near 20 meters depth, and had a complex vertical structure.

A common index for nonlinearity of tides is the ratio of the M4 and M2 constituents. Table 5 yields a ratio of 0.04 for the pressure gauge and ratios of kinetic energy for the currents were 0.09. These numbers are far below those for regimes considered to be highly nonlinear due to frictional effects.

This being the case, I investigated the ability of a simple hydraulic model for Golden Gate currents (USDOC, 1950). This model relates the pressure difference across the channel to the observed currents.

In Figure 33 the height differences from Point Reyes, to seaward of Golden Gate, and Alameda, landward of Golden Gate, are compared to along channel currents with a two hour lag. When the heights are higher at Point Reyes, flood tides occur on the order of three knots per half meter of height difference.

As these hydraulically forced tidal currents pass through the Golden Gate they were "steered". Golden Gate currents demonstrated three levels of steering. Although surface measurements were not made, the near surface bin of the ADCP, 12 meters, had a clear "S" shaped pattern in the along and cross channel component scatter plot (see Figure 12). The "S" shape pattern at 12 meters had less along channel extent and greater cross channel variability than at deeper depths. The ebb flow had greater cross channel flow, starting with a strong northward component, then developing into a broad offshore flow with weak oscillating northward and southward components. The flood developed progressively into a broad sweeping pattern with a more dominate northward cross channel component. In the midlayer, the "S" pattern was very narrow and elongated, indicating near rectilinear flow. Finally, at the near bottom layer, 84 meters depth, the "S" pattern deforms into a "M" shape.

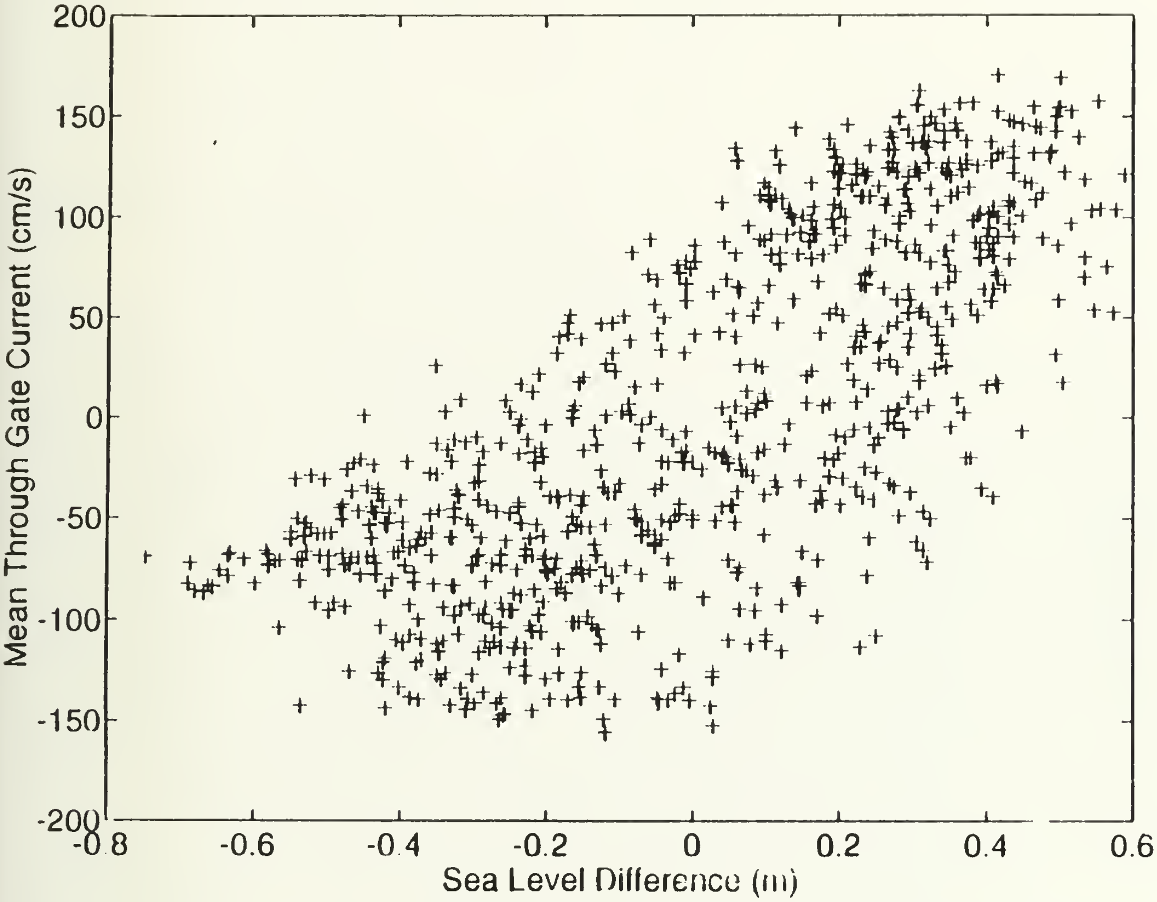


Figure 33. Sea Level Difference to Mean Along Channel Currents between Pt. Reyes and Alameda as measured by NOAA tide gauges. Currents lag heights by two hours.

At the bottom, both the flood and ebb had strong northward components early in their development which gave way to broad sweeping currents with near equal and oscillating northward and southward components.

During the period of observations, waters of the Gate clearly cooled and freshened. Figure 3 showed a deeper cooler surface layer on 4 December than 9 November. The overall profile on 4 December was cooler and fresher than on 9 November. Figure 4a showed a general cooling trend in excess of 0.02° C per day from mid November until early December. In early December a series of storms occurred and the cooling trend reversed for about three days then resumed. During the November cooling phase the salinity remained fairly constant. Figure 4b revealed tidal oscillations about a mean salinity of 31.5 psu. When the December storms occur the salinity drops rapidly, reaching a low of 29.6 psu by the end of the record. Salinity and temperature fluctuations observed at depth are clearly related to horizontal gradients. Salinity variability retained a tidal character throughout the measurement, freshening almost 1 psu on each ebb. The horizontal (and vertical) temperature stratification was clearly affected by the storms of early December and associated release of fresh water into the Bay. The normal cooling of 1° C that occurred with each flood disappeared completely. The independence of events affecting the water column was demonstrated by the daily TS values. Early in the record the TS values proceed almost vertically down on the TS plot indicating long term (seasonal) cooling. The storms from 2 to 10 December have two major impacts on the Bay. First, and most obvious, is the release of fresh water into the Gate which causes rapid freshening of the Bay. This freshening showed on the TS plot as a nearly horizontal line at the end of the record. The second influence is the lack of temperature stratification in the water column. Figure 7 clearly showed surface and subsurface temperatures which were about the same. Following the storm period, the phase of the diurnal surface temperatures changed, indicating a reversal of the horizontal temperature gradient.

Subtidal flows were analyzed qualitatively using stacked plots of smoothed variables and cross correlation functions. The stack plots showed a meteorological forcing early in the record that damped with depth, Figures 18 and 19. Persistent southeastward winds enhanced the along channel flood through almost the entire water column during the first week of the deployment. During this same period a lower level perturbation occurred but did not propagate toward the surface.

A series of strong storm events late in the record caused tidal modification through the depth of the water column. Strong eastward winds enhanced the floods and westward enhanced the ebbs.

Cross channel flow analysis supported the theory that fresher waters exited near the surface on the north side of the Golden Gate and denser waters enter following the depths to the south (Conomos et al, 1985). The near surface cross channel currents showed strong northward tendencies. From 60 to 84 meters the flow was predominately southward. Foreman's tidal current analysis indicated general counter clockwise rotation of the shallow water constituents. This also supported the northward component of the near surface currents.

Analysis of the high frequency information revealed the continued presence of an along channel 5 hour period signal. This is close to the period of the 2MK5. The persistent detided 5 hour signal, is not an internal wave. The 5 hour signal also had a phase shift from decreasing positive from 12 to 60 meters then increasingly negative to the bottom. The 5 hour signal is probably a nonlinear or nonstationary response to tidal forcing, notably the 2MK5 constituent.

A possible quarter wave seiche was evident from the spectral analysis of the along channel high frequency information. A 1.67 hour period, frequency 0.01 cpm, signal was evident. The quarter wave seiche response of the central bay:

$$T_c = \frac{4L_c}{\sqrt{gh}}$$

reasonably ranged from 0.5 to 2 hours, depending on values of depth and length used (Pond and Pickard, 1991 and Chuang and Boicourt, 1989).

ADCP and bottom CTD data were decimated to six minute samples and used to estimate volume and energy flows at the mooring site (Figure 34). The coordinate system used for this calculation was a positive rotation of 5.5 degrees, the average of the rotations determined by minimizing the cross channel variance.

The volume flux was estimated by vertically summing the along channel currents. The velocity of the bottom layer was assumed to be one half that of the deepest ADCP bin and the velocity of the surface layer was set equal to the velocity of the upper ADCP bin.

This yielded a mean volume flux along a 1-m wide column at our measurement site of 21 m^3/s. This flux is integrated through the measurement period in Figure 34a.

The kinetic energy flux through this same 1-m wide column was estimated using the same approximations for the surface and bottom layer as were used for the volume flux. For this calculation we also assumed that the water column was homogeneous and used the density measured by the bottom mounted CTD. The mean kinetic energy flux was 2.8×10^4 W. This energy flux is integrated through the measurement period in Figure 34b.

The energy flux due to the work done by pressure was estimated by assuming hydrostatic equilibrium and neglecting the effects of the changes of density within the water column. The mean energy flux was 8.5×10^6 W. If this energy flux is the same at other locations across the channel (given our volume flux results, there is little reason to expect this to be so), the total energy flux through the Golden Gate would be 8.5×10^9 W.

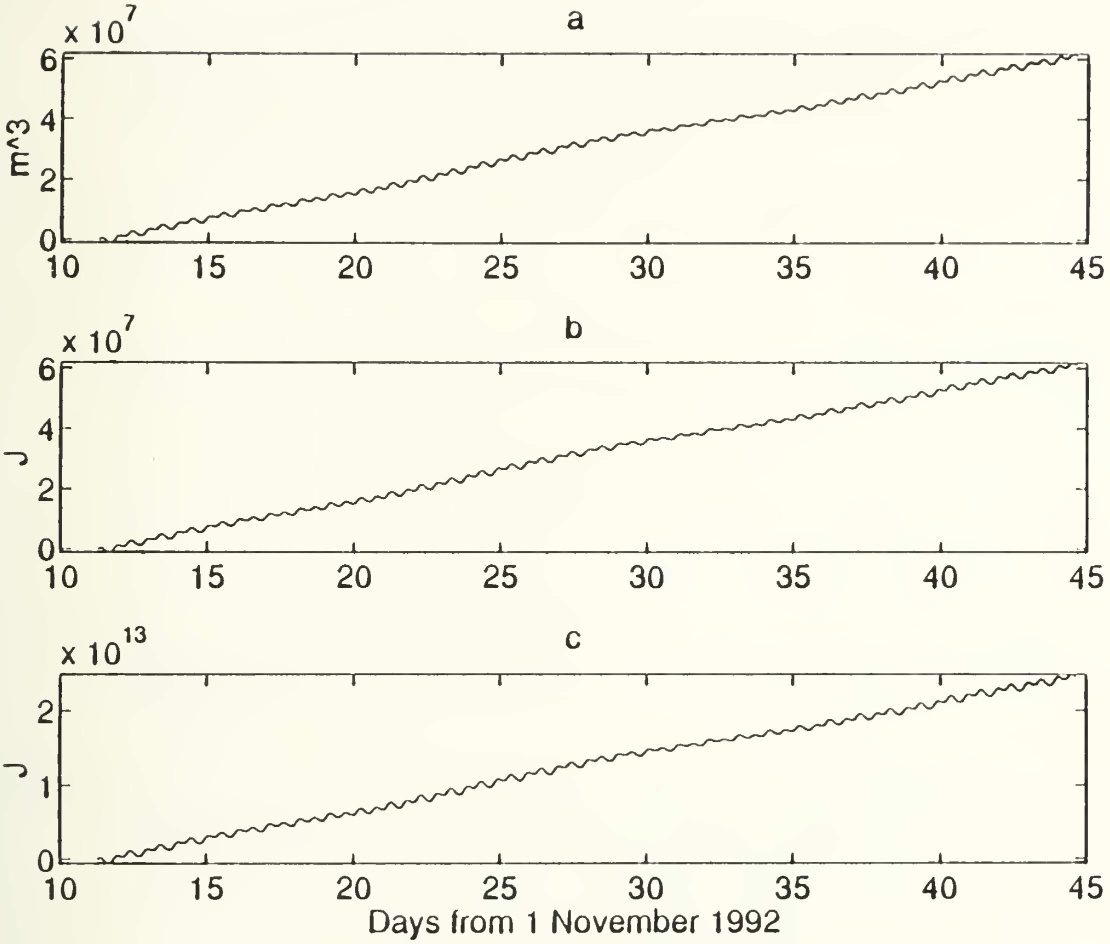


Figure 34. Transports through the Golden Gate into San Francisco Bay. Fluxes are calculated along 094.5° T and through a one-meter wide column at SFB1 and integrated through the measurement period. (Total transports for the Golden Gate would be 10^3 greater than these transports if the same flow, density, and pressure structure occurred at other locations across this section)

a. Volume
b. Work due to Kinetic energy transport
c. Work due to pressure

To gain a more meaningful understanding of the true dynamics in Golden Gate a multisensor collection effort is required. A spread of no less than four ADCP's is required to box the seaward and landward approaches to the Golden Gate. If available a fifth ADCP should be placed at the center of this grid. This deployment should include moored CTD's on each ADCP frame and regular CTD profile casts. A surface temperature and salinity monitor (similar to the Fort Point sensor) should be temporarily employed on the north side of the Golden Gate. Finally, the deployment should last for no less than 34 days.

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APPENDIX A

INSTRUMENT SETUP AND DETAILS

I. INSTRUMENT PACKAGE AND DEPLOYMENT

The instrument package consisted of one Self-Contained Acoustic Doppler Current Profiler (ADCP), RD Instruments Inc., and one SEACAT SBE 16 Conductivity-Temperature-Depth (CTD), Sea-Bird Electronics, Inc. The ADCP was secured in a steel protective cage via a gimble mechanism designed to lock in place after 24 hours to ensure near vertical alignment of the transducer assembly. The CTD was mounted on the cage frame such that it was at the same level as the transducer heads of the ADCP. 11 standard glass floats where mounted about the frame to provide positive buoyancy once the concrete anchor was released via dual acoustic release devices. A second Seabird CTD was used to record water column profiles. The second CTD was secured to 90 meters of line and hand tended from the surface. One meter of line with four 10 lb steel balls was attached to the lower end of the CTD to reduce kiting.

II. The SC-ADCP

The SC-ADCP, manufactured by RD Instruments Inc., is a modular instrument consisting of a watertight transducer assembly which operates at an acoustic frequency of 307 kHz, and a pressure case that houses the EPROM recorder, battery packs, pitch and roll sensors, fluxgate compass, and a high resolution temperature sensor. The ADCP was deployed from 09 November to 15 December 1992 at site SFB1. The mooring started in 100m of water but was accidently dragged by a fishing vessel on 12 November 1992 to about 91m. The final mooring position could not be accurately determined, but appeared to be slightly shoreward and into the Bay with respect to the original position. The ADCP measured velocity by doppler shift comparison of four beams. Details of ADCP velocity calculations and errors are explained in detail by Johns, 1988, RD Instruments, 1989 and 1992, and Abbott, 1991. The ADCP was programmed to record an ensemble average of 180, 1-second acoustic pulses, or pings, every three minutes. ADCP internal clock was set to GMT by Naval Observatory Master Time check. ADCP internal clock was compared to the Naval Observatory Master time on recovery of data and no error was observed. Data was recorded in Beam coordinates then transformed to Earth coordinates for analysis.

The three-minute reduced averaging yielded standard deviation of random error velocity to 1.0 cm/s, equal to instrument bias (RD Instruments, 1992).

The ADCP segmented the velocity profile into uniform depths (depth cells or bins) by range gating the return from each ping. Thirty 4-meter bins were recorded for each of the 16844 usable ensembles. The values of echo amplitude for all four beams at each depth level were averaged over the length of the deployment. The amplitude of the signal decreases as a function of range from the transducer heads, except near the surface layer. The echo from an acoustic hard surface - in this case the surface - is much stronger than those from the scatterers in the water column. With each transducer head angled at 30 degrees from the vertical, the echo contamination will return to the ADCP at the same time as the echo from the main lobe at 85 percent of the distance to the surface. This overwhelms the side-lobe suppression and degrades the quality of the data. Corresponding maximum ranges for mooring SFB1 yields a rejection of data from the surface to 12 meters deep (RD Instruments, 1992). Adjacent cells were not statistically independent because of overlap from the sliding digital filter, which caused a correlation between adjacent cells of 0.15 (RD Instruments, 1989). Where statistical independence was required, only the odd numbered bins were used.

A surface track ping was programmed to determine surface elevation. This function is normally used when the instrument is hull mounted and looking down for bottom tracking. Due to scatter and sidelobe contamination, this information proved to be too inaccurate for analysis and well below acceptable percent good limits.

The stored data, consisting of header and current information, were downloaded and initially analyzed by the "Transect" program provided by RD Instruments. The current data was converted into ASCII format utilizing a module of the "Transect" program, then transferred to a UNIX workstation and put in matrix form to facilitate detailed MATLAB processing and analysis.

III. SEACAT CTD

The SEACAT SBE 16 CTD manufactured by Sea-Bird Electronics, Inc., is a modular instrument designed to measure and record electrical conductivity, temperature, and pressure with high levels of accuracy and resolution. SEACAT CTD accuracies and resolutions are listed in Table A-1 (Sea-Bird, 1992). The SEACAT CTD's interfaced through standard Sea-Bird software, SEASOFT, to either Lap Top computer or Desk Top, IBM 286 compatible. Detailed analysis was performed on UNIX workstations using MATLAB. Both the SEACAT sensors used a Pyrex cell and pressure-protected thermistor, a Paroscientific Digiquartz pressure sensor and a Wein-bridge oscillator enclosed in a sealed aluminum housing.

A. Moored SEACAT CTD

This CTD was mounted to the upper framework of the ADCP protective cage. The CTD was vertically displaced 5 cm below the ADCP transducer heads. Sampling rate was set at once every 2 minutes.

B. The Profiling SEACAT CTD

The second SEACAT CTD recorded water column CTD profiles. Two profiles were recovered by hand lowering a weighted CTD on 90 meters of line. Profile recording was set at twice per second. Profiles were collected on 09 November from the ADCP deployment vessel, USCG Blackhaw, and on 04 December from a small boat. CTD data listings are included as Table A-2.

IV. CTD Calibration

To calibrate both SEACAT CTDs, bottle salts were collected near the surface from the deployment vessels and compared to the recorded data from the CTDs.

A. Moored CTD calibration

The bottle salts from 9 November were measured twice and averaged, which yielded a "true" salinity of 32.243 psu. Five of the moored CTD's near surface salinity recordings were averaged for comparison, yielding a "measured" salinity of 32.564 psu. Thus, the difference between the bottle and mounted CTD salts was -0.321 psu. This correction was applied to the moored CTD salinity data.

B. 09 Nov Profiling CTD calibration

The same process as above was applied to compare the bottle salts and the profiling CTD salinity data. Only the CTD downcasts were used for data analysis. The profiling CTD average near surface salinity was 31.0451 psu, yielding a difference of +1.198 psu. This was added to the profiling CTD salinity.

C. 04 December Profiling CTD calibration

On 04 December, 1992 a second profile was collected from a N.P.S. owned Boston Whaler. Bottle salts and CTD data were compared using the above procedure. The "true" salt was 31.228 psu, while the salt measured by the CTD was 31.470 psu. This required 0.242 psu to be subtracted from the CTD data. As before, only the CTD downcast data was processed.

D. Moored CTD to Profiling CTD: bottom salts

The moored CTD's salinity could not be compared to that of the profiling CTD's. While the moored CTD was 91 meters deep, the profiling CTD never exceeded 87 meters. Salinity and temperature measured by the moored CTD (91 meters) and profiling CTD (82 meters on 9 November, 87 meters on 4 December) were on the same order of magnitude as listed in Table A-3.

TABLE A-1
CTD ACCURACY, RESOLUTION, AND SUPPORT INFORMATION

Accuracy:	Temperature	0.01 °C/6 months
	Conductivity	0.001 S/m/month
	Pressure	0.02% of full scale range
Resolution:	Temperature	0.001 °C
	Conductivity	0.0001 S/m
	Pressure	0.0003% of full scale (moored) 0.006% of full scale (profile)
Counter time-base	Quartz TCXO, +/-2 ppm per year aging; +/-2 ppm vs. temperature (-5 to +30 °C).	
Real-time clock	Watch-crystal type 32,768 Hz; battery backed for minimum of 1 year operation irrespective of condition of main battery. Corrected for drift and aging by comparison to SEACAT counter time-base.	

TABLE A-2
CTD DATA LISTINGS

In the following table, station data are listed in numerical order. The specific volume anomaly (δ) is calculated using the algorithms found in Volume 4 of the International Oceanographic Tables (UNESCO, 1987). The units for δ are 10^{-8} m^{3} kg^{-1}. The summation of dynamic height ($\sum\Delta D$) is made from the surface and the units are in dynamic meters (0.1 m^{2} s^{-2}).

Data listings at selected pressures of temperature (°C), salinity (psu), density anomaly (kg m^{-3}), specific volume anomaly (δ), summation of dynamic height ($\sum\Delta D$), and spiciness (π) for CTD profiles collected on 09 November and 04 December 1992 near station SFB1.

STATION: SFB1 DATE: 09 November 1992 1800 GMT
LAT: 37 49.0 N. LON: 122 28.0 W.

P(dbar)	T(°C)	S(psu)	γ_θ(kg m^{-3})	δ	$\sum\Delta D$	π
0.1	15.664	32.240	23.800	410.62	0.001	0.060
2.0	14.451	32.574	24.220	369.17	0.007	0.084
4.0	14.441	32.600	24.242	367.05	0.015	0.103
6.0	14.426	32.618	24.259	365.53	0.022	0.113
8.0	14.572	32.488	24.128	378.05	0.030	0.041
10.0	14.357	32.692	24.331	358.78	0.037	0.157
12.0	14.275	32.784	24.419	350.41	0.044	0.213
14.0	14.192	32.829	24.471	345.56	0.051	0.230
16.0	14.301	32.746	24.384	353.86	0.058	0.188
18.0	14.258	32.758	24.402	352.20	0.065	0.188
20.0	14.165	32.874	24.512	341.83	0.072	0.261
22.0	14.172	32.849	24.491	343.89	0.079	0.242
24.0	14.167	32.837	24.483	344.72	0.086	0.231
26.0	14.777	32.267	23.916	398.82	0.093	-0.091
28.0	19.147	27.173	19.071	860.51	0.100	-3.209
30.0	14.387	32.663	24.303	362.02	0.108	0.140
32.0	14.225	32.837	24.471	346.03	0.115	0.244
34.0	14.072	32.975	24.610	332.89	0.122	0.321
36.0	15.042	32.111	23.741	415.77	0.129	-0.158
38.0	15.316	31.816	23.457	442.88	0.137	-0.335
40.0	15.780	31.895	23.423	446.19	0.145	-0.173
42.0	14.023	33.027	24.660	328.33	0.151	0.351
44.0	13.915	33.053	24.702	324.37	0.158	0.348
46.0	14.100	32.902	24.548	339.11	0.165	0.268
48.0	14.638	32.341	24.003	390.99	0.171	-0.063
50.0	13.763	33.244	24.881	307.49	0.178	0.468
52.0	14.117	32.842	24.498	344.03	0.185	0.224
54.0	13.952	33.011	24.663	328.37	0.191	0.323

56.0	13.947	33.065	24.705	324.42	0.198	0.364
58.0	13.941	33.058	24.701	324.87	0.204	0.357
60.0	13.925	33.043	24.693	325.69	0.211	0.342
62.0	13.914	33.057	24.706	324.47	0.217	0.351
64.0	13.922	33.098	24.736	321.70	0.224	0.385
66.0	13.951	33.084	24.720	323.30	0.230	0.380
68.0	13.932	33.119	24.750	320.46	0.237	0.404
70.0	13.910	33.130	24.763	319.25	0.243	0.408
72.0	13.930	33.141	24.768	318.91	0.250	0.421
74.0	13.919	32.981	24.647	330.43	0.256	0.292
76.0	13.896	33.048	24.704	325.11	0.263	0.340
78.0	13.928	33.072	24.716	324.02	0.269	0.366
80.0	13.930	33.053	24.700	325.57	0.276	0.350
82.0	13.918	33.065	24.712	324.44	0.282	0.358
82.4	13.918	33.061	24.709	324.78	0.284	0.354

STATION: SFB1 DATE: 04 November 1992 2100 GMT
LAT: 37 49.0 N. LON: 122 28.0 W.

P(dbar)	T(°C)	S(psu)	γ_θ(kg m^{-3})	δ	$\sum\Delta D$	π
1.1	13.236	31.224	23.424	445.03	0.005	-1.271
2.0	13.238	31.215	23.417	445.75	0.009	-1.278
4.0	13.221	31.243	23.442	443.37	0.018	-1.259
6.0	13.199	31.300	23.491	438.79	0.027	-1.216
8.0	13.193	31.346	23.527	435.34	0.035	-1.180
10.0	13.187	31.385	23.559	432.40	0.044	-1.149
12.0	13.184	31.425	23.590	429.46	0.053	-1.118
14.0	13.177	31.517	23.663	422.57	0.061	-1.043
16.0	13.172	31.558	23.695	419.52	0.070	-1.012
18.0	13.172	31.557	23.695	419.63	0.078	-1.012
20.0	13.174	31.550	23.689	420.23	0.086	-1.018
22.0	13.176	31.538	23.679	421.22	0.095	-1.028
24.0	13.178	31.520	23.665	422.59	0.103	-1.041
26.0	13.180	31.511	23.658	423.36	0.112	-1.048
28.0	13.182	31.508	23.655	423.66	0.120	-1.051
30.0	13.183	31.506	23.653	423.88	0.129	-1.052
32.0	13.183	31.505	23.653	423.97	0.137	-1.053
34.0	13.183	31.508	23.655	423.77	0.146	-1.050
36.0	13.184	31.510	23.657	423.68	0.154	-1.048
38.0	13.185	31.509	23.655	423.87	0.163	-1.050
40.0	13.176	31.548	23.687	420.86	0.171	-1.020
42.0	13.166	31.575	23.711	418.69	0.179	-0.999
44.0	13.168	31.553	23.693	420.42	0.188	-1.017
46.0	13.170	31.537	23.680	421.67	0.196	-1.030
48.0	13.169	31.545	23.687	421.12	0.205	-1.024
50.0	13.171	31.538	23.681	421.71	0.213	-1.029
52.0	13.171	31.537	23.680	421.83	0.222	-1.030
54.0	13.172	31.545	23.686	421.31	0.230	-1.023
56.0	13.170	31.563	23.700	420.00	0.238	-1.009
58.0	13.171	31.564	23.702	419.94	0.247	-1.008
60.0	13.172	31.561	23.699	420.25	0.255	-1.010
62.0	13.172	31.561	23.699	420.31	0.264	-1.010
64.0	13.172	31.565	23.702	420.08	0.272	-1.007
66.0	13.172	31.561	23.699	420.41	0.280	-1.010
68.0	13.171	31.569	23.705	419.85	0.289	-1.004
70.0	13.173	31.559	23.697	420.66	0.297	-1.012
72.0	13.174	31.554	23.693	421.07	0.306	-1.016
74.0	13.174	31.561	23.699	420.63	0.314	-1.010
76.0	13.173	31.571	23.707	419.88	0.322	-1.002
78.0	13.174	31.571	23.707	419.95	0.331	-1.002
80.0	13.173	31.581	23.714	419.28	0.339	-0.994
82.0	13.175	31.603	23.732	417.67	0.348	-0.976
84.0	13.175	31.602	23.731	417.80	0.356	-0.976
86.0	13.175	31.600	23.729	418.05	0.364	-0.979
87.8	13.175	31.618	23.743	416.74	0.372	-0.964

TABLE A-3
NEAR BOTTOM CTD AND PROFILING CTD TEMPERATURE AND SALINITY

	09 Nov		04 Dec	
	moored	profile	moored	profile
Salinity (psu)	32.60	33.06	31.63	31.62
Temperature (° C)	15.0	13.9	13.2	13.2
Depth (m)	91	82	91	87

APPENDIX B

FOREMAN TIDAL ANALYSIS

I. GENERAL DESCRIPTION

Using the assumption that a tidal signal is the sum of a series of harmonic terms having certain relations to astronomical conditions (USDOC, 1950). These harmonic terms are called "constituents". The Foreman tidal analysis scheme performs a least squares fit coupled with nodal modulation on hourly current meter or tide height data to calculate current ellipse parameters and Greenwich phase lags (Foreman, 1978) or tidal amplitudes and Greenwich phase lags (Foreman, 1977) for these constituents. A standard package of 69 constituents with 77 additional shallow water constituents can be requested for computation. The programs only resolve those constituents that the record length will support. Additional constituents may be inferred on request from resolvable constituents.

II. DATA ANALYSIS

In order to use the Foreman programs, the data from the ADCP had to be reformatted. The data --- currents, heights, temperatures, salinities --- were in matrix format (as required by MATLAB) so a subsampling scheme common for all data (with minor variations per parameter) was used. The subsampling program shown below was repeated for each odd numbered depth bin twenty times, advancing the time step once each run. Although the program below was specifically used on the current data, the subsampling routines were very similar for all the data sets. There were no gaps in the hourly records.

```
uh#=u#(116:20:16220);
vh#=v#(116:20:16220);
uh#=uh#(1:792);
vh#=vh#(1:792);
uh#=reshape(uh#,12,66);
vh#=reshape(vh#,12,66);
urh#=zeros(66,15);
vrh#=zeros(66,15);
urh#(:,1)=urh#(:,1)+1;
vrh#(:,1)=vrh#(:,1)+1;
urh#(2:2:66,1)=urh#(2:2:66,1)+1;
vrh#(2:2:66,1)=vrh#(2:2:66,1)+1;
urh#(:,2)=urh#(:,2)+1109;
vrh#(:,2)=vrh#(:,2)+1109;
urh#(:,3)=date;
vrh#(:,3)=date;
urh#(:,4:15)=uh#';
vrh#(:,4:15)=vh#';
```

The result was twenty records for each depth bin, which represented an hourly subsample of the entire 33 day record, each time stepped every 3 minutes. Each record was exported from MATLAB using the following program:

```
fid=fopen('urhl.ask','w')
fprintf(fid,'%1.0f %5.0f %12.0f %4.0f %4.0f ...
%4.0f %4.0f %4.0f %4.0f %4.0f %4.0f %4.0f ...
%4.0f %4.0f %4.0f\n',urh#')
```

Minor word processing was required for some header information prior to Foreman analysis. The Foreman programs determined the constituents and predicted the "pure" tide signal for each record. The pressure signal from the moored CTD was used for height analysis and the Foreman analyzed constituents are listed in Table B-1. The following tide gauge data were received from NOAA, tides analyzed, and are included as tabular data: San Francisco (Table B-2), Alameda (Table B-3), Port Chicago (Table B-4), and Point Reyes (Table B-5). The moored CTD temperature and salinity data were also analyzed by the Foreman heights analysis program.

Tables B-1 through B-5 have five columns. The first column is the constituent alpha numeric abreviation (see Godin, 1972). Column 2 is the constituent frequency in cycles per hour. STN is an arbitrary station identification number. The fourth column lists the start and stop month and year of the data set analyzed. AL, GL, A, and G are the amplitudes (hundredths of unit) and phases (degrees) obtained for each constituent and the same amplitudes and phases after nodal correction for astronomical adjustment (Foreman, 1977).

Horizontal current data from the ADCP - U and V components - were analyzed by the Foreman Current Analysis program. Tabular Foreman current constituent ellipses for each depth bin listed in Tables B-6 through B-15. In Tables B-6 through B-15 eight columns of results are listed. Columns one and two are the constituent name and frequency in cycles per hour. MAJOR and MINOR are the semimajor axis and semiminor axis of the tidal constituent's elipse. INC is the inclination of the elipse from 090° T (positive clockwise). G is the phase shift of the epoch relative to Greenwich. G+ and G- are the counter-rotating vectors that describe the tidal ellipse (Foreman, 1978). Constituents marked "INF" did not have sufficient record length for analysis but were inferred from resolvable constituents (Foreman, 1978).

TABLE B-1
CTD MEASURED TIDE HEIGHTS ANALYSIS

ANALYSIS OF HOURLY TIDAL HEIGHTS STN 1109 1H 12/11/92 TO 24H 14/12/92
NO.OBS.= 792 NO.PTS.ANAL.= 792 MIDPT=12H 28/11/92 SEPARATION =1.00

NO	NAME	FREQUENCY	STN	M-Y/ M-Y	A	G		AL	GL
1	Z0	0.00000000	1109	1192/1292	9.1578	0.00		9.1578	0.00
2	MM	0.00151215	1109	1192/1292	0.0038	215.86		0.0038	79.23
3	MSF	0.00282193	1109	1192/1292	0.0019	340.28		0.0019	252.66
4	ALP1	0.03439657	1109	1192/1292	0.0011	244.25		0.0011	4.95
5	2Q1	0.03570635	1109	1192/1292	0.0004	310.10		0.0004	119.70
6	Q1	0.03721850	1109	1192/1292	0.0039	287.74		0.0038	320.47
7	O1	0.03873065	1109	1192/1292	0.0243	296.61		0.0241	192.58
8	NO1	0.04026859	1109	1192/1292	0.0005	262.86		0.0006	220.51
9	P1	0.04155259	1109	1192/1292	0.0000	308.81	INF FR K1	0.0000	105.74
10	K1	0.04178075	1109	1192/1292	0.0468	309.14		0.0467	142.59
11	J1	0.04329290	1109	1192/1292	0.0024	298.63		0.0024	350.53
12	OO1	0.04483084	1109	1192/1292	0.0006	339.20		0.0006	278.26
13	UPS1	0.04634299	1109	1192/1292	0.0005	17.38		0.0006	181.93
14	EPS2	0.07617731	1109	1192/1292	0.0006	68.29		0.0006	20.83
15	MU2	0.07768947	1109	1192/1292	0.0008	219.53		0.0008	33.37
16	N2	0.07899925	1109	1192/1292	0.0094	0.65		0.0095	222.63
17	M2	0.08051140	1109	1192/1292	0.0591	27.76		0.0595	113.19
18	L2	0.08202355	1109	1192/1292	0.0011	78.10		0.0009	199.15
19	S2	0.08333334	1109	1192/1292	0.0114	32.72		0.0114	32.84
20	K2	0.08356149	1109	1192/1292	0.0000	32.45	INF FR S2	0.0000	239.17
21	ETA2	0.08507364	1109	1192/1292	0.0002	36.62		0.0002	93.21
22	MO3	0.11924206	1109	1192/1292	0.0017	342.02		0.0017	323.42
23	M3	0.12076710	1109	1192/1292	0.0004	302.10		0.0004	70.36
24	MK3	0.12229215	1109	1192/1292	0.0019	29.51		0.0019	308.39
25	SK3	0.12511408	1109	1192/1292	0.0004	12.69		0.0004	206.26
26	MN4	0.15951064	1109	1192/1292	0.0007	75.70		0.0007	23.11
27	M4	0.16102280	1109	1192/1292	0.0023	141.66		0.0023	312.52
28	SN4	0.16233259	1109	1192/1292	0.0003	168.51		0.0003	30.62
29	MS4	0.16384473	1109	1192/1292	0.0009	106.16		0.0009	191.71
30	S4	0.16666667	1109	1192/1292	0.0002	34.36		0.0002	34.61
31	2MK5	0.20280355	1109	1192/1292	0.0006	91.07		0.0006	95.38
32	2SK5	0.20844743	1109	1192/1292	0.0004	356.01		0.0004	189.71
33	2MN6	0.24002205	1109	1192/1292	0.0005	347.99		0.0005	20.83
34	M6	0.24153420	1109	1192/1292	0.0004	129.06		0.0004	25.35
35	2MS6	0.24435613	1109	1192/1292	0.0004	221.33		0.0004	32.32
36	2SM6	0.24717808	1109	1192/1292	0.0004	141.86		0.0004	227.54
37	3MK7	0.28331494	1109	1192/1292	0.0004	135.73		0.0004	225.47
38	M8	0.32204559	1109	1192/1292	0.0003	24.34		0.0003	6.06
39	M10	0.40255699	1109	1192/1292	0.0004	147.64		0.0004	214.80

TABLE B-2
SAN FRANCISCO BAY TIDE HEIGHTS ANALYSIS

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NALYSIS OF HOURLY TIDAL HEIGHTS  STN  1109     1H 12/11/92 TO  24H 14/12/92
O.OBS.=    792    NO.PTS.ANAL.=    792     MIDPT=12H 28/11/92  SEPARATION =1.00

NO NAME      FREQUENCY    STN  M-Y/ M-Y        A       G                     AL      GL
 1 Z0       0.00000000  1109 1192/1292  2.8071    0.00                  2.8071    0.00
 2 MM       0.00151215  1109 1192/1292  0.0706  242.55                  0.0706  105.92
 3 MSF      0.00282193  1109 1192/1292  0.0578  296.77                  0.0578  209.15
 4 ALP1     0.03439657  1109 1192/1292  0.0037   94.47                  0.0037  215.18
 5 2Q1      0.03570635  1109 1192/1292  0.0059   80.30                  0.0059  249.90
 6 Q1       0.03721850  1109 1192/1292  0.0328  106.60                  0.0328  139.32
 7 O1       0.03873065  1109 1192/1292  0.2316  113.66                  0.2298    9.63
 8 NO1      0.04026859  1109 1192/1292  0.0038   43.93                  0.0051    1.59
 9 P1       0.04155259  1109 1192/1292  0.0000  111.12 INF FR K1        0.0000  268.05
10 K1       0.04178075  1109 1192/1292  0.4517  111.45                  0.4513  304.90
11 J1       0.04329290  1109 1192/1292  0.0194  111.22                  0.0193  163.13
12 OO1      0.04483084  1109 1192/1292  0.0063  106.84                  0.0071   45.91
13 UPS1     0.04634299  1109 1192/1292  0.0038  190.76                  0.0040  355.31
14 EPS2     0.07617731  1109 1192/1292  0.0018   25.28                  0.0018  337.81
15 MU2      0.07768947  1109 1192/1292  0.0080  186.25                  0.0081    0.09
16 N2       0.07899925  1109 1192/1292  0.1004  343.62                  0.1013  205.60
17 M2       0.08051140  1109 1192/1292  0.5917    5.79                  0.5951   91.22
18 L2       0.08202355  1109 1192/1292  0.0099    2.83                  0.0079  123.88
19 S2       0.08333334  1109 1192/1292  0.1062  358.42                  0.1062  358.55
20 K2       0.08356149  1109 1192/1292  0.0000  358.15 INF FR S2        0.0000  204.87
21 ETA2     0.08507364  1109 1192/1292  0.0039  356.31                  0.0039   52.91
22 MO3      0.11924206  1109 1192/1292  0.0177  139.63                  0.0177  121.04
23 M3       0.12076710  1109 1192/1292  0.0073   83.08                  0.0074  211.34
24 MK3      0.12229215  1109 1192/1292  0.0221  165.22                  0.0222   84.10
25 SK3      0.12511408  1109 1192/1292  0.0047  130.71                  0.0047  324.29
26 MN4      0.15951064  1109 1192/1292  0.0063   87.79                  0.0064   35.20
27 M4       0.16102280  1109 1192/1292  0.0203   97.30                  0.0206  268.16
28 SN4      0.16233259  1109 1192/1292  0.0031   73.18                  0.0031  295.28
29 MS4      0.16384473  1109 1192/1292  0.0056   62.48                  0.0056  148.03
30 S4       0.16666667  1109 1192/1292  0.0018  304.47                  0.0018  304.71
31 2MK5     0.20280355  1109 1192/1292  0.0106  226.42                  0.0108  230.74
32 2SK5     0.20844743  1109 1192/1292  0.0023  244.54                  0.0023   78.23
33 2MN6     0.24002205  1109 1192/1292  0.0018  283.71                  0.0018  316.55
34 M6       0.24153420  1109 1192/1292  0.0012  127.56                  0.0013   23.85
35 2MS6     0.24435613  1109 1192/1292  0.0012   61.80                  0.0012  232.78
36 2SM6     0.24717808  1109 1192/1292  0.0003  326.45                  0.0003   52.12
37 3MK7     0.28331494  1109 1192/1292  0.0018    0.79                  0.0018   90.53
38 M8       0.32204559  1109 1192/1292  0.0015   89.49                  0.0015   71.21
39 M10      0.40255699  1109 1192/1292  0.0014  294.92                  0.0014    2.07
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TABLE B-3
ALAMEDA TIDE HEIGHTS ANALYSIS

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ANALYSIS OF HOURLY TIDAL HEIGHTS  STN  1109     1H 12/11/92 TO  24H 14/12/92
NO.OBS.=   792    NO.PTS.ANAL.=   792    MIDPT=12H 28/11/92  SEPARATION =1.00

 NO NAME     FREQUENCY    STN  M-Y/ M-Y         A       G                       AL      GL
  1 Z0     0.00000000   1109 1192/1292  2.0857   0.00                     2.0857   0.00
  2 MM     0.00151215   1109 1192/1292  0.0685 245.88                     0.0685 109.25
  3 MSF    0.00282193   1109 1192/1292  0.0561 302.45                     0.0561 214.83
  4 ALP1   0.03439657   1109 1192/1292  0.0019 101.77                     0.0019 222.48
  5 2Q1    0.03570635   1109 1192/1292  0.0064  79.81                     0.0064 249.41
  6 Q1     0.03721850   1109 1192/1292  0.0319 118.56                     0.0319 151.29
  7 O1     0.03873065   1109 1192/1292  0.2306 121.60                     0.2288  17.58
  8 NO1    0.04026859   1109 1192/1292  0.0023  71.40                     0.0031  29.05
  9 P1     0.04155259   1109 1192/1292  0.0000 118.76 INF FR K1           0.0000 275.69
 10 K1     0.04178075   1109 1192/1292  0.4595 119.09                     0.4591 312.54
 11 J1     0.04329290   1109 1192/1292  0.0180 124.51                     0.0180 176.42
 12 OO1    0.04483084   1109 1192/1292  0.0067 102.84                     0.0075  41.90
 13 UPS1   0.04634299   1109 1192/1292  0.0035 193.00                     0.0037 357.54
 14 EPS2   0.07617731   1109 1192/1292  0.0044 124.83                     0.0045  77.36
 15 MU2    0.07768947   1109 1192/1292  0.0190 173.69                     0.0192 347.53
 16 N2     0.07899925   1109 1192/1292  0.1097   2.01                     0.1106 223.99
 17 M2     0.08051140   1109 1192/1292  0.6902  21.12                     0.6942 106.55
 18 L2     0.08202355   1109 1192/1292  0.0210  17.13                     0.0166 138.18
 19 S2     0.08333334   1109 1192/1292  0.1165  18.11                     0.1165  18.24
 20 K2     0.08356149   1109 1192/1292  0.0000  17.84 INF FR S2           0.0000 224.56
 21 ETA2   0.08507364   1109 1192/1292  0.0048 347.45                     0.0049  44.05
 22 MO3    0.11924206   1109 1192/1292  0.0282 131.36                     0.0282 112.76
 23 M3     0.12076710   1109 1192/1292  0.0089  75.90                     0.0089 204.16
 24 MK3    0.12229215   1109 1192/1292  0.0225 147.10                     0.0226  65.98
 25 SK3    0.12511408   1109 1192/1292  0.0035 121.92                     0.0035 315.50
 26 MN4    0.15951064   1109 1192/1292  0.0036 103.93                     0.0037  51.34
 27 M4     0.16102280   1109 1192/1292  0.0116 101.06                     0.0118 271.92
 28 SN4    0.16233259   1109 1192/1292  0.0035  42.68                     0.0036 264.78
 29 MS4    0.16384473   1109 1192/1292  0.0034   6.01                     0.0034  91.57
 30 S4     0.16666667   1109 1192/1292  0.0006 262.36                     0.0006 262.60
 31 2MK5   0.20280355   1109 1192/1292  0.0176 218.75                     0.0178 223.06
 32 2SK5   0.20844743   1109 1192/1292  0.0005 343.28                     0.0005 176.97
 33 2MN6   0.24002205   1109 1192/1292  0.0020 104.69                     0.0021 137.53
 34 M6     0.24153420   1109 1192/1292  0.0070 150.03                     0.0071  46.32
 35 2MS6   0.24435613   1109 1192/1292  0.0019 162.29                     0.0019 333.27
 36 2SM6   0.24717808   1109 1192/1292  0.0004 218.14                     0.0004 303.82
 37 3MK7   0.28331494   1109 1192/1292  0.0036 216.27                     0.0037 306.02
 38 M8     0.32204559   1109 1192/1292  0.0011  26.66                     0.0011   8.38
 39 M10    0.40255699   1109 1192/1292  0.0009 316.49                     0.0010  23.64
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TABLE B-4
PORT CHICAGO TIDE HEIGHTS ANALYSIS

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ANALYSIS OF HOURLY TIDAL HEIGHTS  STN  1109     1H 12/11/92 TO  24H 14/12/92
NO.OBS.=   792    NO.PTS.ANAL.=   792    MIDPT=12H 28/11/92  SEPARATION =1.00

 NO NAME     FREQUENCY   STN  M-Y/ M-Y       A      G                    AL     GL
  1 Z0     0.00000000  1109 1192/1292  1.9603   0.00              1.9603   0.00
  2 MM     0.00151215  1109 1192/1292  0.0837 270.78              0.0837 134.15
  3 MSF    0.00282193  1109 1192/1292  0.0906 339.28              0.0906 251.66
  4 ALP1   0.03439657  1109 1192/1292  0.0038  87.67              0.0038 208.37
  5 2Q1    0.03570635  1109 1192/1292  0.0075 102.04              0.0075 271.64
  6 Q1     0.03721850  1109 1192/1292  0.0163 177.01              0.0163 209.74
  7 O1     0.03873065  1109 1192/1292  0.1454 163.46              0.1443  59.43
  8 NO1    0.04026859  1109 1192/1292  0.0052 312.96              0.0069 270.62
  9 P1     0.04155259  1109 1192/1292  0.0000 160.12 INF FR K1    0.0000 317.05
 10 K1     0.04178075  1109 1192/1292  0.3263 160.45              0.3260 353.90
 11 J1     0.04329290  1109 1192/1292  0.0019 249.94              0.0019 301.85
 12 OO1    0.04483084  1109 1192/1292  0.0148 137.89              0.0165  76.96
 13 UPS1   0.04634299  1109 1192/1292  0.0035 282.43              0.0037  86.97
 14 EPS2   0.07617731  1109 1192/1292  0.0054 183.30              0.0055 135.83
 15 MU2    0.07768947  1109 1192/1292  0.0311 242.07              0.0314  55.92
 16 N2     0.07899925  1109 1192/1292  0.0682  61.07              0.0687 283.05
 17 M2     0.08051140  1109 1192/1292  0.4887  82.69              0.4916 168.12
 18 L2     0.08202355  1109 1192/1292  0.0219  84.71              0.0173 205.75
 19 S2     0.08333334  1109 1192/1292  0.0607  79.54              0.0607  79.66
 20 K2     0.08356149  1109 1192/1292  0.0000  79.26 INF FR S2    0.0000 285.98
 21 ETA2   0.08507364  1109 1192/1292  0.0038  39.94              0.0039  96.54
 22 MO3    0.11924206  1109 1192/1292  0.0503 184.34              0.0502 165.74
 23 M3     0.12076710  1109 1192/1292  0.0124 102.75              0.0125 231.01
 24 MK3    0.12229215  1109 1192/1292  0.0428 178.91              0.0430  97.79
 25 SK3    0.12511408  1109 1192/1292  0.0077 173.50              0.0077   7.07
 26 MN4    0.15951064  1109 1192/1292  0.0038  36.94              0.0038 344.35
 27 M4     0.16102280  1109 1192/1292  0.0090  61.89              0.0091 232.75
 28 SN4    0.16233259  1109 1192/1292  0.0007 168.54              0.0007  30.65
 29 MS4    0.16384473  1109 1192/1292  0.0131 108.88              0.0131 194.43
 30 S4     0.16666667  1109 1192/1292  0.0009 289.64              0.0009 289.89
 31 2MK5   0.20280355  1109 1192/1292  0.0315  46.54              0.0319  50.85
 32 2SK5   0.20844743  1109 1192/1292  0.0004 114.16              0.0004 307.85
 33 2MN6   0.24002205  1109 1192/1292  0.0049 316.06              0.0050 348.90
 34 M6     0.24153420  1109 1192/1292  0.0097   0.62              0.0099 256.91
 35 2MS6   0.24435613  1109 1192/1292  0.0035 316.31              0.0035 127.29
 36 2SM6   0.24717808  1109 1192/1292  0.0008 162.48              0.0008 248.15
 37 3MK7   0.28331494  1109 1192/1292  0.0033 105.00              0.0034 194.74
 38 M8     0.32204559  1109 1192/1292  0.0010   3.35              0.0010 345.07
 39 M10    0.40255699  1109 1192/1292  0.0008 334.75              0.0008  41.90
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TABLE B-5
POINT REYES TIDE HEIGHTS ANALYSIS

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ANALYSIS OF HOURLY TIDAL HEIGHTS  STN  1109      1H 12/11/92 TO  24H 14/12/92
NO.OBS.=    792    NO.PTS.ANAL.=    792    MIDPT=12H 28/11/92  SEPARATION =1.00

 NO NAME     FREQUENCY    STN  M-Y/ M-Y        A       G                        AL      GL
  1 Z0      0.00000000  1109 1192/1292  2.2196   0.00                      2.2196   0.00
  2 MM      0.00151215  1109 1192/1292  0.0803 237.67                      0.0803 101.04
  3 MSF     0.00282193  1109 1192/1292  0.0581 303.90                      0.0581 216.28
  4 ALP1    0.03439657  1109 1192/1292  0.0013 105.40                      0.0013 226.11
  5 2Q1     0.03570635  1109 1192/1292  0.0039  91.47                      0.0039 261.07
  6 Q1      0.03721850  1109 1192/1292  0.0351 104.83                      0.0351 137.55
  7 O1      0.03873065  1109 1192/1292  0.2352 107.48                      0.2334   3.45
  8 NO1     0.04026859  1109 1192/1292  0.0059 345.64                      0.0079 303.29
  9 P1      0.04155259  1109 1192/1292  0.0000 103.60 INF FR K1            0.0000 260.53
 10 K1      0.04178075  1109 1192/1292  0.4683 103.93                      0.4679 297.38
 11 J1      0.04329290  1109 1192/1292  0.0301  99.55                      0.0301 151.46
 12 OO1     0.04483084  1109 1192/1292  0.0110 162.95                      0.0123 102.02
 13 UPS1    0.04634299  1109 1192/1292  0.0030  99.90                      0.0032 264.44
 14 EPS2    0.07617731  1109 1192/1292  0.0032 248.58                      0.0032 201.11
 15 MU2     0.07768947  1109 1192/1292  0.0107 242.45                      0.0108  56.29
 16 N2      0.07899925  1109 1192/1292  0.0879 322.55                      0.0886 184.53
 17 M2      0.08051140  1109 1192/1292  0.5507 347.93                      0.5539  73.36
 18 L2      0.08202355  1109 1192/1292  0.0180 212.70                      0.0143 333.75
 19 S2      0.08333334  1109 1192/1292  0.1120 336.91                      0.1120 337.03
 20 K2      0.08356149  1109 1192/1292  0.0000 336.63 INF FR S2            0.0000 183.35
 21 ETA2    0.08507364  1109 1192/1292  0.0031 160.85                      0.0031 217.45
 22 MO3     0.11924206  1109 1192/1292  0.0021 171.15                      0.0021 152.55
 23 M3      0.12076710  1109 1192/1292  0.0031  68.43                      0.0031 196.68
 24 MK3     0.12229215  1109 1192/1292  0.0037 219.16                      0.0037 138.05
 25 SK3     0.12511408  1109 1192/1292  0.0022 295.96                      0.0022 129.53
 26 MN4     0.15951064  1109 1192/1292  0.0023 134.34                      0.0023  81.75
 27 M4      0.16102280  1109 1192/1292  0.0010 217.42                      0.0010  28.28
 28 SN4     0.16233259  1109 1192/1292  0.0016 147.99                      0.0016  10.09
 29 MS4     0.16384473  1109 1192/1292  0.0054  49.89                      0.0054 135.45
 30 S4      0.16666667  1109 1192/1292  0.0030 352.66                      0.0030 352.90
 31 2MK5    0.20280355  1109 1192/1292  0.0035 284.77                      0.0036 289.08
 32 2SK5    0.20844743  1109 1192/1292  0.0024 117.22                      0.0024 310.91
 33 2MN6    0.24002205  1109 1192/1292  0.0030 195.71                      0.0030 228.55
 34 M6      0.24153420  1109 1192/1292  0.0054 122.09                      0.0055  18.38
 35 2MS6    0.24435613  1109 1192/1292  0.0043 145.93                      0.0043 316.92
 36 2SM6    0.24717808  1109 1192/1292  0.0043 199.10                      0.0044 284.78
 37 3MK7    0.28331494  1109 1192/1292  0.0033  51.70                      0.0033 141.45
 38 M8      0.32204559  1109 1192/1292  0.0031 206.84                      0.0032 188.56
 39 M10     0.40255699  1109 1192/1292  0.0004 314.71                      0.0004  21.86
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TABLE B-6
TIDAL CURRENT ANALYSIS @ 12 METERS

FOR STATION 1109, SFB1 GOLDEN GATE BRDG ,AT THE LOCATION 37 49, 122 27
OVER THE PERIOD OF 1HR 12/11/92 TO 24H
GREENWICH PHASES ARE FOR TIME ZONE GMT

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-	
1	Z0	0.00000000	0.742	0.000	9.0	360.0	351.0	9.0	
2	MM	0.00151215	3.855	-0.559	137.5	215.7	78.2	353.2	
3	MSF	0.00282193	4.396	-0.089	1.1	1.6	0.5	2.7	
4	ALP1	0.03439657	0.817	0.275	39.6	147.1	107.5	186.6	
5	2Q1	0.03570635	2.608	-1.984	168.3	146.0	337.6	314.3	
6	Q1	0.03721850	1.430	-0.849	31.8	124.8	93.1	156.6	
7	O1	0.03873065	6.552	3.276	25.6	156.3	130.7	181.8	
8	NO1	0.04026859	1.397	-0.707	93.0	247.4	154.4	340.4	
9	P1	0.04155259	5.455	1.239	2.1	179.8	177.8	181.9	INF FR K1
10	K1	0.04178075	21.402	0.066	4.2	177.5	173.3	181.7	
11	J1	0.04329290	2.748	-1.058	45.6	143.3	97.7	188.9	
12	OO1	0.04483084	3.069	0.042	66.4	211.0	144.7	277.4	
13	UPS1	0.04634299	0.944	0.374	92.8	276.0	183.2	8.8	
14	EPS2	0.07617731	1.185	-0.074	33.5	272.6	239.1	306.2	
15	MU2	0.07768947	3.691	0.169	46.5	341.7	295.2	28.2	
16	N2	0.07899925	14.156	1.947	15.7	169.4	153.7	185.1	
17	M2	0.08051140	81.691	-1.958	179.1	5.6	186.4	184.7	
18	L2	0.08202355	4.074	0.187	149.5	32.0	242.5	181.5	
19	S2	0.08333334	17.423	0.327	-2.0	197.3	199.2	195.3	
20	K2	0.08356149	3.522	-0.115	157.0	11.1	214.0	168.1	INF FR S2
21	ETA2	0.08507364	1.390	1.084	90.9	289.1	198.1	20.0	
22	MO3	0.11924206	7.521	-1.083	171.8	210.0	38.2	21.8	
23	M3	0.12076710	3.227	-1.476	142.7	168.2	25.5	310.9	
24	MK3	0.12229215	13.471	-1.691	170.6	196.9	26.4	7.5	
25	SK3	0.12511408	1.405	0.711	38.7	351.6	312.9	30.3	
26	MN4	0.15951064	3.099	0.034	146.3	166.5	20.2	312.8	
27	M4	0.16102280	14.419	-1.076	168.3	207.9	39.6	16.2	
28	SN4	0.16233259	2.949	0.646	176.7	205.6	28.9	22.3	
29	MS4	0.16384473	3.060	0.972	137.5	168.4	30.9	305.9	
30	S4	0.16666667	2.615	-0.543	52.1	69.9	17.8	121.9	
31	2MK5	0.20280355	5.933	-2.824	90.8	193.8	103.0	284.6	
32	2SK5	0.20844743	1.577	0.349	51.6	317.1	265.5	8.7	
33	2MN6	0.24002205	2.485	-0.429	152.2	254.9	102.7	47.0	
34	M6	0.24153420	6.963	-0.088	115.8	269.7	154.0	25.5	
35	2MS6	0.24435613	0.695	0.296	50.1	310.3	260.2	0.3	
36	2SM6	0.24717808	1.689	0.070	104.8	352.9	248.1	97.7	
37	3MK7	0.28331494	7.257	-1.202	119.3	75.7	316.4	195.0	
38	M8	0.32204559	1.985	-0.761	80.7	107.4	26.6	188.1	
39	M10	0.40255699	0.774	0.039	0.4	93.2	92.7	93.6	

TABLE B-7
TIDAL CURRENT ANALYSIS @ 20 METERS

FOR STATION 1109, SFB1 GOLDEN GATE BRDG ,AT THE LOCATION 37 49, 122 27
OVER THE PERIOD OF 1HR 12/11/92 TO 24H
GREENWICH PHASES ARE FOR TIME ZONE GMT

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-	
1	Z0	0.00000000	0.697	0.000	170.2	180.0	9.8	350.2	
2	MM	0.00151215	4.559	-1.062	138.2	217.6	79.4	355.8	
3	MSF	0.00282193	4.307	0.357	179.6	182.2	2.6	1.8	
4	ALP1	0.03439657	0.900	0.202	19.5	130.6	111.2	150.1	
5	2Q1	0.03570635	2.808	-1.770	179.4	135.7	316.3	315.2	
6	Q1	0.03721850	1.290	-1.083	56.1	86.8	30.7	142.9	
7	O1	0.03873065	6.644	2.987	14.3	144.4	130.1	158.7	
8	NO1	0.04026859	1.080	-0.641	99.8	233.5	133.7	333.4	
9	P1	0.04155259	5.962	1.303	1.0	179.3	178.3	180.3	INF FR K1
10	K1	0.04178075	23.441	-0.143	3.1	177.0	173.8	180.1	
11	J1	0.04329290	2.662	-1.029	39.2	144.1	105.0	183.3	
12	OO1	0.04483084	2.756	0.048	64.2	209.2	145.1	273.4	
13	UPS1	0.04634299	1.062	0.975	68.7	252.9	184.3	321.6	
14	EPS2	0.07617731	1.006	-0.199	22.5	278.8	256.3	301.2	
15	MU2	0.07768947	3.926	0.177	42.1	340.1	298.1	22.2	
16	N2	0.07899925	15.262	1.752	14.3	168.1	153.9	182.4	
17	M2	0.08051140	89.115	-1.626	179.3	5.9	186.6	185.2	
18	L2	0.08202355	4.649	-0.073	152.2	35.1	243.0	187.3	
19	S2	0.08333334	18.735	0.294	-4.3	196.6	200.9	192.2	
20	K2	0.08356149	3.788	-0.135	154.7	10.4	215.7	165.0	INF FR S2
21	ETA2	0.08507364	1.418	1.177	120.8	317.5	196.7	78.3	
22	MO3	0.11924206	7.905	-1.339	174.0	206.5	32.5	20.5	
23	M3	0.12076710	3.254	-1.631	139.9	168.4	28.5	308.3	
24	MK3	0.12229215	14.049	-1.924	173.2	193.0	19.7	6.2	
25	SK3	0.12511408	1.351	0.749	62.8	7.7	305.0	70.5	
26	MN4	0.15951064	3.466	0.090	152.2	157.5	5.3	309.7	
27	M4	0.16102280	15.813	-2.173	172.5	205.6	33.0	18.1	
28	SN4	0.16233259	3.422	0.451	4.9	27.7	22.7	32.6	
29	MS4	0.16384473	3.173	1.080	146.4	171.3	24.9	317.6	
30	S4	0.16666667	2.496	-0.596	54.7	68.5	13.7	123.2	
31	2MK5	0.20280355	6.005	-2.976	97.8	185.6	87.8	283.4	
32	2SK5	0.20844743	1.479	0.379	55.8	327.9	272.1	23.7	
33	2MN6	0.24002205	3.058	-0.371	164.2	250.6	86.5	54.8	
34	M6	0.24153420	7.409	0.169	121.3	270.5	149.1	31.8	
35	2MS6	0.24435613	0.767	0.443	97.7	1.0	263.3	98.7	
36	2SM6	0.24717808	2.098	0.064	109.8	343.5	233.7	93.3	
37	3MK7	0.28331494	7.830	-1.180	127.6	77.1	309.6	204.7	
38	M8	0.32204559	1.821	-1.291	99.7	104.3	4.6	204.0	
39	M10	0.40255699	1.018	0.152	161.3	267.7	106.3	69.0	

TABLE B-8
TIDAL CURRENT ANALYSIS @ 28 METERS

FOR STATION 1109, SFB1 GOLDEN GATE BRDG ,AT THE LOCATION 37 49, 122 27
OVER THE PERIOD OF 1HR 12/11/92 TO 24H
GREENWICH PHASES ARE FOR TIME ZONE GMT

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-	
1	Z0	0.00000000	0.780	0.000	172.3	180.0	7.7	352.3	
2	MM	0.00151215	3.635	-0.832	143.6	218.1	74.5	1.8	
3	MSF	0.00282193	3.231	0.563	173.7	180.8	7.1	354.4	
4	ALP1	0.03439657	0.940	-0.046	161.0	298.7	137.7	99.6	
5	2Q1	0.03570635	2.315	-1.177	147.0	149.8	2.8	296.8	
6	Q1	0.03721850	0.978	-0.595	117.0	355.5	238.5	112.5	
7	O1	0.03873065	10.068	1.767	12.7	147.3	134.6	159.9	
8	NO1	0.04026859	1.148	-0.461	147.7	192.4	44.7	340.1	
9	P1	0.04155259	7.052	1.339	0.4	176.9	176.5	177.3	INF FR K1
10	K1	0.04178075	27.914	-1.002	2.5	174.6	172.0	177.1	
11	J1	0.04329290	2.078	-0.826	47.4	142.0	94.6	189.4	
12	OO1	0.04483084	2.452	0.359	50.0	201.5	151.4	251.5	
13	UPS1	0.04634299	0.930	0.743	79.7	277.4	197.6	357.1	
14	EPS2	0.07617731	0.880	-0.519	12.5	305.6	293.0	318.1	
15	MU2	0.07768947	3.631	0.353	41.8	349.3	307.4	31.1	
16	N2	0.07899925	17.072	1.215	10.3	165.5	155.2	175.8	
17	M2	0.08051140	98.442	-0.507	179.3	6.9	187.6	186.2	
18	L2	0.08202355	4.656	-0.789	151.8	14.4	222.6	166.2	
19	S2	0.08333334	20.789	0.093	-5.8	195.3	201.1	189.5	
20	K2	0.08356149	4.206	-0.197	153.2	9.1	215.9	162.3	INF FR S2
21	ETA2	0.08507364	1.667	1.038	21.2	225.7	204.5	247.0	
22	MO3	0.11924206	7.586	-0.248	171.7	210.2	38.5	21.9	
23	M3	0.12076710	2.492	-1.187	141.5	160.2	18.7	301.7	
24	MK3	0.12229215	13.146	-1.448	166.0	197.5	31.5	3.5	
25	SK3	0.12511408	1.106	0.161	69.7	15.4	305.7	85.2	
26	MN4	0.15951064	3.113	-0.162	159.9	152.8	353.0	312.7	
27	M4	0.16102280	15.213	-2.753	170.4	203.9	33.5	14.3	
28	SN4	0.16233259	2.953	-0.171	172.4	214.0	41.6	26.4	
29	MS4	0.16384473	3.353	1.565	153.0	175.0	22.0	328.0	
30	S4	0.16666667	2.098	-0.662	58.0	68.6	10.6	126.6	
31	2MK5	0.20280355	5.806	-1.264	94.1	176.5	82.4	270.5	
32	2SK5	0.20844743	1.213	0.211	81.2	354.0	272.8	75.2	
33	2MN6	0.24002205	2.267	-0.478	145.1	252.0	106.9	37.1	
34	M6	0.24153420	6.440	0.811	124.2	272.0	147.8	36.2	
35	2MS6	0.24435613	0.676	-0.567	173.3	334.2	160.9	147.5	
36	2SM6	0.24717808	1.826	-0.167	129.0	337.5	208.5	106.4	
37	3MK7	0.28331494	7.149	-1.245	121.3	86.8	325.5	208.1	
38	M8	0.32204559	1.296	-0.826	160.2	75.8	275.5	236.0	
39	M10	0.40255699	0.881	0.096	133.6	280.5	146.9	54.2	

TABLE B-9
TIDAL CURRENT ANALYSIS @ 36 METERS

FOR STATION 1109, SFB1 GOLDEN GATE BRDG ,AT THE LOCATION 37 49, 122 27
OVER THE PERIOD OF 1HR 12/11/92 TO 24H
GREENWICH PHASES ARE FOR TIME ZONE GMT

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-	
1	Z0	0.00000000	0.486	0.000	179.3	180.0	0.7	359.3	
2	MM	0.00151215	2.324	-0.218	149.5	219.5	70.0	9.0	
3	MSF	0.00282193	2.648	0.431	157.9	185.6	27.7	343.4	
4	ALP1	0.03439657	1.161	-0.039	142.4	285.6	143.3	68.0	
5	2Q1	0.03570635	1.925	-0.976	138.0	140.7	2.7	278.7	
6	Q1	0.03721850	0.285	-0.205	103.5	8.0	264.6	111.5	
7	O1	0.03873065	13.317	1.217	10.8	150.0	139.2	160.8	
8	NO1	0.04026859	1.516	-0.089	149.6	197.4	47.9	347.0	
9	P1	0.04155259	7.963	1.333	179.5	355.3	175.8	174.8	INF FR K1
10	K1	0.04178075	31.687	-1.875	1.6	172.9	171.3	174.6	
11	J1	0.04329290	2.262	-0.304	37.6	160.6	123.1	198.2	
12	OO1	0.04483084	2.012	0.364	41.6	193.8	152.2	235.5	
13	UPS1	0.04634299	1.023	0.570	138.2	318.4	180.2	96.6	
14	EPS2	0.07617731	0.794	-0.475	73.8	260.6	186.8	334.4	
15	MU2	0.07768947	4.000	0.282	37.6	2.5	324.9	40.1	
16	N2	0.07899925	18.761	1.225	9.0	165.5	156.5	174.5	
17	M2	0.08051140	106.550	0.467	179.1	7.7	188.6	186.8	
18	L2	0.08202355	4.392	-1.117	152.8	4.3	211.5	157.1	
19	S2	0.08333334	22.533	-0.266	-5.9	194.2	200.1	188.3	
20	K2	0.08356149	4.563	-0.288	153.1	8.0	214.9	161.1	INF FR S2
21	ETA2	0.08507364	1.969	0.987	18.9	219.6	200.7	238.5	
22	MO3	0.11924206	7.365	0.590	170.4	220.3	49.9	30.7	
23	M3	0.12076710	2.099	-0.976	143.2	147.1	3.9	290.3	
24	MK3	0.12229215	12.355	-0.501	159.5	203.6	44.0	3.1	
25	SK3	0.12511408	1.013	-0.090	51.7	28.7	337.0	80.5	
26	MN4	0.15951064	2.773	0.345	163.9	156.1	352.3	320.0	
27	M4	0.16102280	12.845	-2.823	169.7	203.9	34.1	13.6	
28	SN4	0.16233259	3.260	-0.200	163.2	219.2	56.0	22.4	
29	MS4	0.16384473	2.975	1.787	148.9	181.1	32.3	330.0	
30	S4	0.16666667	2.105	-0.588	60.1	58.2	358.0	118.3	
31	2MK5	0.20280355	5.599	1.083	83.3	168.2	84.9	251.6	
32	2SK5	0.20844743	0.840	-0.242	94.8	359.9	265.1	94.7	
33	2MN6	0.24002205	2.179	-0.352	121.7	256.2	134.5	17.8	
34	M6	0.24153420	5.762	1.136	126.5	279.1	152.5	45.6	
35	2MS6	0.24435613	1.099	-0.268	15.0	134.4	119.4	149.3	
36	2SM6	0.24717808	1.829	-0.257	143.9	335.8	191.9	119.7	
37	3MK7	0.28331494	6.206	-0.824	105.9	97.2	351.2	203.1	
38	M8	0.32204559	1.533	-0.546	170.7	93.8	283.1	264.6	
39	M10	0.40255699	0.970	0.266	95.9	292.6	196.7	28.6	

TABLE B-10
TIDAL CURRENT ANALYSIS @ 44 METERS

FOR STATION 1109, SFB1 GOLDEN GATE BRDG ,AT THE LOCATION 37 49, 122 27
OVER THE PERIOD OF 1HR 12/11/92 TO 24H
GREENWICH PHASES ARE FOR TIME ZONE GMT

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-	
1	Z0	0.00000000	0.772	0.000	0.5	360.0	359.5	0.5	
2	MM	0.00151215	3.809	0.027	123.6	229.9	106.2	353.5	
3	MSF	0.00282193	2.125	0.139	1.5	15.1	13.7	16.6	
4	ALP1	0.03439657	0.902	0.326	21.1	118.1	97.0	139.2	
5	2Q1	0.03570635	2.033	-0.719	72.5	233.3	160.9	305.8	
6	Q1	0.03721850	1.296	0.050	77.4	68.4	351.1	145.8	
7	O1	0.03873065	15.841	3.208	8.3	152.7	144.4	161.0	
8	NO1	0.04026859	1.631	-1.033	146.3	207.3	61.0	353.6	
9	P1	0.04155259	8.633	1.864	0.1	174.3	174.2	174.3	INF FR K1
10	K1	0.04178075	33.966	-0.300	2.2	171.9	169.7	174.1	
11	J1	0.04329290	2.513	-0.918	50.6	133.0	82.5	183.6	
12	OO1	0.04483084	3.223	0.786	65.7	202.0	136.3	267.7	
13	UPS1	0.04634299	1.202	0.825	119.5	291.3	171.8	50.8	
14	EPS2	0.07617731	0.983	-0.504	6.3	321.1	314.8	327.4	
15	MU2	0.07768947	4.033	-1.145	40.2	356.3	316.0	36.5	
16	N2	0.07899925	19.322	2.139	10.9	165.8	154.9	176.7	
17	M2	0.08051140	112.987	-1.999	179.3	8.1	188.8	187.4	
18	L2	0.08202355	4.258	-1.125	159.6	3.4	203.8	163.1	
19	S2	0.08333334	23.801	0.103	-2.9	195.8	198.7	193.0	
20	K2	0.08356149	4.815	-0.226	156.1	9.6	213.5	165.8	INF FR S2
21	ETA2	0.08507364	2.562	1.165	7.1	210.7	203.5	217.8	
22	MO3	0.11924206	7.163	-1.066	168.7	230.9	62.2	39.6	
23	M3	0.12076710	2.412	-1.480	106.7	193.9	87.1	300.6	
24	MK3	0.12229215	10.800	-1.413	169.1	208.2	39.1	17.3	
25	SK3	0.12511408	1.869	-0.555	40.3	47.8	7.5	88.0	
26	MN4	0.15951064	2.930	-0.077	148.7	164.5	15.8	313.3	
27	M4	0.16102280	10.895	-1.535	167.6	203.8	36.2	11.4	
28	SN4	0.16233259	2.754	0.557	9.1	41.9	32.8	51.0	
29	MS4	0.16384473	2.694	1.661	139.5	178.3	38.8	317.8	
30	S4	0.16666667	2.383	-0.215	61.9	62.3	0.4	124.1	
31	2MK5	0.20280355	6.034	3.561	84.2	190.5	106.3	274.6	
32	2SK5	0.20844743	1.358	-0.052	100.1	330.0	229.9	70.1	
33	2MN6	0.24002205	1.417	-0.472	133.8	257.1	123.2	30.9	
34	M6	0.24153420	7.315	1.968	115.6	276.7	161.0	32.3	
35	2MS6	0.24435613	1.570	-0.501	156.1	305.2	149.1	101.2	
36	2SM6	0.24717808	2.310	-0.440	117.0	338.9	221.9	95.9	
37	3MK7	0.28331494	6.311	-0.371	94.9	79.8	344.9	174.7	
38	M8	0.32204559	2.680	0.134	130.6	110.3	339.7	240.9	
39	M10	0.40255699	0.398	-0.164	142.1	112.7	330.5	254.8	

TABLE B 11
TIDAL CURRENT ANALYSIS @ 52 METERS

FOR STATION 1109, SFB1 GOLDEN GATE BRDG ,AT THE LOCATION 37 49, 122 27
OVER THE PERIOD OF 1HR 12/11/92 TO 24H
GREENWICH PHASES ARE FOR TIME ZONE GMT

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-	
1	Z0	0.00000000	0.838	0.000	178.9	180.0	1.1	358.9	
2	MM	0.00151215	2.148	-0.284	20.1	49.7	29.6	69.8	
3	MSF	0.00282193	3.356	0.821	135.5	192.6	57.1	328.1	
4	ALP1	0.03439657	1.679	-0.165	141.4	300.4	159.0	81.8	
5	2Q1	0.03570635	1.049	-0.424	132.0	120.5	348.5	252.6	
6	Q1	0.03721850	0.794	0.524	174.7	286.5	111.8	101.2	
7	O1	0.03873065	16.548	0.862	9.5	153.3	143.8	162.7	
8	NO1	0.04026859	1.824	0.265	142.7	189.8	47.1	332.4	
9	P1	0.04155259	8.738	1.526	178.0	353.7	175.6	171.7	INF FR K1
10	K1	0.04178075	34.713	-1.793	0.2	171.3	171.1	171.5	
11	J1	0.04329290	2.430	0.351	38.7	164.4	125.6	203.1	
12	OO1	0.04483084	1.737	0.066	14.9	177.1	162.2	192.0	
13	UPS1	0.04634299	0.777	0.619	159.6	309.1	149.5	108.7	
14	EPS2	0.07617731	1.329	-0.492	39.0	294.0	255.0	333.0	
15	MU2	0.07768947	3.599	-0.393	33.8	0.5	326.7	34.3	
16	N2	0.07899925	19.412	1.039	8.1	164.5	156.4	172.5	
17	M2	0.08051140	115.026	0.962	179.1	8.3	189.1	187.4	
18	L2	0.08202355	4.446	-1.117	146.7	6.8	220.1	153.6	
19	S2	0.08333334	23.855	-0.774	-6.1	196.3	202.4	190.2	
20	K2	0.08356149	4.835	-0.404	152.9	10.1	217.2	163.0	INF FR S2
21	ETA2	0.08507364	2.476	0.922	5.3	204.4	199.0	209.7	
22	MO3	0.11924206	7.335	0.986	170.7	230.7	59.9	41.4	
23	M3	0.12076710	2.369	-0.404	154.5	138.0	343.5	292.5	
24	MK3	0.12229215	11.164	0.191	156.2	208.9	52.6	5.1	
25	SK3	0.12511408	1.897	-0.537	177.7	242.2	64.6	59.9	
26	MN4	0.15951064	2.609	0.963	170.2	163.2	353.0	333.4	
27	M4	0.16102280	9.894	-1.093	175.4	203.0	27.6	18.3	
28	SN4	0.16233259	2.711	-0.616	153.2	222.0	68.8	15.1	
29	MS4	0.16384473	2.413	0.853	173.0	201.4	28.5	14.4	
30	S4	0.16666667	1.379	-0.473	63.7	35.2	331.5	98.9	
31	2MK5	0.20280355	6.111	2.086	42.3	131.9	89.6	174.3	
32	2SK5	0.20844743	0.509	-0.173	99.3	20.4	281.2	119.7	
33	2MN6	0.24002205	1.971	-0.126	119.3	248.5	129.2	7.8	
34	M6	0.24153420	4.289	1.759	144.9	294.9	149.9	79.8	
35	2MS6	0.24435613	1.752	0.604	7.1	103.7	96.6	110.8	
36	2SM6	0.24717808	0.642	0.048	170.5	307.3	136.8	117.8	
37	3MK7	0.28331494	4.227	-0.476	89.6	112.4	22.8	202.0	
38	M8	0.32204559	2.051	0.072	165.3	113.0	307.6	278.3	
39	M10	0.40255699	1.858	-0.168	77.8	286.7	208.9	4.5	

TABLE B-12
TIDAL CURRENT ANALYSIS @ 60 METERS

FOR STATION 1109, SFB1 GOLDEN GATE BRDG ,AT THE LOCATION 37 49, 122 27
OVER THE PERIOD OF 1HR 12/11/92 TO 24H
GREENWICH PHASES ARE FOR TIME ZONE GMT

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-	
1	Z0	0.00000000	0.941	0.000	3.7	360.0	356.3	3.7	
2	MM	0.00151215	2.200	-0.309	35.9	44.8	8.9	80.7	
3	MSF	0.00282193	4.034	0.814	128.7	195.0	66.3	323.7	
4	ALP1	0.03439657	1.536	-0.225	145.0	302.4	157.4	87.3	
5	2Q1	0.03570635	0.803	0.331	5.6	298.7	293.1	304.3	
6	Q1	0.03721850	1.914	0.960	17.2	129.2	112.0	146.5	
7	O1	0.03873065	16.465	0.820	9.2	154.4	145.1	163.6	
8	NO1	0.04026859	1.749	0.204	130.9	182.2	51.3	313.0	
9	P1	0.04155259	8.739	1.660	177.6	353.7	176.1	171.3	INF FR K1
10	K1	0.04178075	34.594	-1.243	-0.2	171.3	171.6	171.1	
11	J1	0.04329290	2.447	0.368	40.5	163.9	123.4	204.4	
12	OO1	0.04483084	1.707	-0.058	9.6	183.0	173.4	192.5	
13	UPS1	0.04634299	0.859	0.246	151.8	315.3	163.5	107.1	
14	EPS2	0.07617731	1.477	0.041	37.6	292.0	254.3	329.6	
15	MU2	0.07768947	3.247	-0.386	31.9	359.0	327.1	30.9	
16	N2	0.07899925	18.986	0.834	6.8	163.9	157.1	170.6	
17	M2	0.08051140	114.834	0.060	179.4	8.2	188.9	187.6	
18	L2	0.08202355	4.714	-1.012	137.1	14.1	237.0	151.2	
19	S2	0.08333334	23.494	-1.131	-6.5	196.5	203.0	190.1	
20	K2	0.08356149	4.766	-0.473	152.5	10.3	217.8	162.9	INF FR S2
21	ETA2	0.08507364	2.312	0.928	169.4	4.9	195.5	174.3	
22	MO3	0.11924206	7.568	0.708	171.4	232.0	60.6	43.3	
23	M3	0.12076710	2.976	0.138	166.0	134.8	328.8	300.8	
24	MK3	0.12229215	10.816	0.317	160.9	209.5	48.6	10.4	
25	SK3	0.12511408	1.982	-0.565	154.0	251.7	97.7	45.8	
26	MN4	0.15951064	2.862	0.861	0.0	354.5	354.4	354.5	
27	M4	0.16102280	9.485	-0.018	178.4	204.0	25.6	22.5	
28	SN4	0.16233259	2.312	-0.542	157.2	214.8	57.6	12.0	
29	MS4	0.16384473	2.294	0.370	178.6	199.5	20.9	18.1	
30	S4	0.16666667	1.162	-0.325	92.3	341.0	248.7	73.3	
31	2MK5	0.20280355	5.867	0.689	27.4	118.4	91.0	145.8	
32	2SK5	0.20844743	0.538	-0.101	49.9	69.8	20.0	119.7	
33	2MN6	0.24002205	1.700	0.154	133.3	251.0	117.7	24.2	
34	M6	0.24153420	3.682	1.691	172.5	310.6	138.1	123.1	
35	2MS6	0.24435613	2.322	0.486	8.3	105.9	97.6	114.2	
36	2SM6	0.24717808	0.392	0.208	143.0	225.8	82.8	8.9	
37	3MK7	0.28331494	2.133	-0.044	91.9	122.9	30.9	214.8	
38	M8	0.32204559	1.854	0.235	167.8	105.6	297.8	273.4	
39	M10	0.40255699	1.561	-0.389	76.5	284.7	208.2	1.2	

TABEL B 13
TIDAL CURRENT ANALYSIS @ 68 METERS

FOR STATION 1109, SFB1 GOLDEN GATE BRDG ,AT THE LOCATION 37 49, 122 27
OVER THE PERIOD OF 1HR 12/11/92 TO 24H
GREENWICH PHASES ARE FOR TIME ZONE GMT

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-	
1	Z0	0.00000000	0.712	0.000	16.5	360.0	343.5	16.5	
2	MM	0.00151215	2.478	-0.237	53.9	40.9	346.9	94.8	
3	MSF	0.00282193	4.469	0.574	124.3	196.1	71.9	320.4	
4	ALP1	0.03439657	1.393	-0.135	151.5	311.5	160.0	103.0	
5	2Q1	0.03570635	1.130	0.305	43.6	339.0	295.4	22.6	
6	Q1	0.03721850	2.478	1.142	25.5	138.2	112.7	163.7	
7	O1	0.03873065	15.979	0.914	7.7	155.0	147.3	162.8	
8	NO1	0.04026859	1.579	0.252	135.8	180.6	44.8	316.4	
9	P1	0.04155259	8.648	1.644	177.3	354.0	176.7	171.3	INF FR K1
10	K1	0.04178075	34.229	-1.223	-0.5	171.6	172.2	171.1	
11	J1	0.04329290	2.248	0.727	18.4	151.2	132.8	169.5	
12	OO1	0.04483084	1.662	0.118	0.1	181.9	181.8	182.1	
13	UPS1	0.04634299	1.211	-0.184	153.0	317.3	164.2	110.3	
14	EPS2	0.07617731	1.396	-0.200	41.4	303.6	262.1	345.0	
15	MU2	0.07768947	2.788	-0.034	28.1	359.7	331.6	27.7	
16	N2	0.07899925	18.541	0.517	5.4	163.1	157.7	168.5	
17	M2	0.08051140	113.479	-1.233	179.7	8.1	188.4	187.8	
18	L2	0.08202355	4.344	-0.786	135.0	21.4	246.4	156.4	
19	S2	0.08333334	23.400	-1.339	-5.7	195.4	201.1	189.7	
20	K2	0.08356149	4.749	-0.514	153.3	9.2	215.9	162.5	INF FR S2
21	ETA2	0.08507364	2.055	0.649	154.0	350.8	196.8	144.8	
22	MO3	0.11924206	7.778	0.668	172.5	231.7	59.3	44.2	
23	M3	0.12076710	2.971	0.545	176.8	135.1	318.2	311.9	
24	MK3	0.12229215	10.690	0.183	168.5	208.6	40.1	17.2	
25	SK3	0.12511408	2.210	-0.471	145.8	250.2	104.5	36.0	
26	MN4	0.15951064	3.160	1.115	5.7	4.6	358.9	10.3	
27	M4	0.16102280	9.403	1.147	4.3	29.1	24.8	33.5	
28	SN4	0.16233259	2.139	-0.901	153.8	213.3	59.5	7.1	
29	MS4	0.16384473	1.974	-0.157	6.4	16.8	10.4	23.1	
30	S4	0.16666667	0.865	-0.202	78.9	320.5	241.6	39.5	
31	2MK5	0.20280355	4.974	-0.486	13.6	119.7	106.1	133.2	
32	2SK5	0.20844743	0.530	0.093	51.6	62.0	10.3	113.6	
33	2MN6	0.24002205	1.664	0.200	148.2	250.5	102.3	38.8	
34	M6	0.24153420	3.690	0.687	13.8	135.1	121.4	148.9	
35	2MS6	0.24435613	2.150	1.017	9.3	104.4	95.1	113.7	
36	2SM6	0.24717808	0.820	0.273	120.3	176.1	55.8	296.4	
37	3MK7	0.28331494	1.070	-0.361	103.2	214.1	110.9	317.3	
38	M8	0.32204559	1.661	0.364	164.0	88.0	284.0	252.0	
39	M10	0.40255699	0.876	-0.672	37.4	328.9	291.5	6.3	

TABLE B-14
TIDAL CURRENT ANALYSIS @ 76 METERS

FOR STATION 1109, SFB1 GOLDEN GATE BRDG ,AT THE LOCATION 37 49, 122 27
OVER THE PERIOD OF 1HR 12/11/92 TO 24H
GREENWICH PHASES ARE FOR TIME ZONE GMT

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-	
1	Z0	0.00000000	0.504	0.000	44.7	0.0	315.3	44.7	
2	MM	0.00151215	2.572	-0.121	51.8	39.5	347.7	91.3	
3	MSF	0.00282193	5.000	0.016	124.5	202.7	78.2	327.1	
4	ALP1	0.03439657	0.688	-0.126	161.8	320.3	158.5	122.1	
5	2Q1	0.03570635	1.646	0.345	55.9	343.4	287.6	39.3	
6	Q1	0.03721850	2.612	0.976	32.6	143.1	110.5	175.7	
7	O1	0.03873065	15.547	0.970	4.5	153.6	149.1	158.1	
8	NO1	0.04026859	1.568	0.339	145.6	186.6	41.1	332.2	
9	P1	0.04155259	8.598	1.616	176.7	353.7	176.9	170.4	INF FR K1
10	K1	0.04178075	34.049	-1.293	-1.1	171.3	172.4	170.2	
11	J1	0.04329290	2.260	0.858	3.5	147.3	143.8	150.8	
12	OO1	0.04483084	1.409	-0.012	154.2	351.3	197.1	145.4	
13	UPS1	0.04634299	1.524	-0.149	151.3	306.7	155.5	98.0	
14	EPS2	0.07617731	1.212	-0.204	38.9	314.2	275.3	353.1	
15	MU2	0.07768947	2.047	0.101	25.8	0.6	334.9	26.4	
16	N2	0.07899925	18.271	-0.121	4.1	162.6	158.5	166.7	
17	M2	0.08051140	111.472	-2.911	179.7	7.8	188.1	187.6	
18	L2	0.08202355	3.946	-0.430	135.0	15.2	240.3	150.2	
19	S2	0.08333334	23.436	-0.939	-5.8	195.3	201.1	189.5	
20	K2	0.08356149	4.752	-0.433	153.2	9.1	215.9	162.3	INF FR S2
21	ETA2	0.08507364	1.833	0.319	141.4	345.8	204.4	127.2	
22	MO3	0.11924206	7.843	0.411	171.5	227.6	56.1	39.2	
23	M3	0.12076710	2.765	0.952	178.1	132.8	314.7	310.9	
24	MK3	0.12229215	10.772	0.127	175.7	208.3	32.6	24.0	
25	SK3	0.12511408	2.591	-0.388	137.6	243.6	106.0	21.2	
26	MN4	0.15951064	3.376	0.968	11.7	13.6	1.9	25.3	
27	M4	0.16102280	9.473	2.433	15.8	39.8	23.9	55.6	
28	SN4	0.16233259	1.846	-0.993	153.9	209.3	55.4	3.2	
29	MS4	0.16384473	2.022	-0.766	6.2	22.8	16.6	29.0	
30	S4	0.16666667	0.594	-0.031	109.2	273.8	164.6	23.1	
31	2MK5	0.20280355	4.458	-1.201	163.2	312.2	149.1	115.4	
32	2SK5	0.20844743	0.566	0.281	46.1	58.9	12.8	105.0	
33	2MN6	0.24002205	1.373	0.230	168.9	267.5	98.6	76.4	
34	M6	0.24153420	3.950	-0.342	34.1	131.5	97.4	165.7	
35	2MS6	0.24435613	2.036	1.336	7.7	109.2	101.4	116.9	
36	2SM6	0.24717808	1.172	0.230	116.9	156.9	40.0	273.8	
37	3MK7	0.28331494	3.312	-0.923	80.9	267.6	186.7	348.4	
38	M8	0.32204559	1.330	0.391	149.9	75.2	285.2	225.1	
39	M10	0.40255699	1.089	-0.049	19.1	1.3	342.1	20.4	

TABLE B-15
TIDAL CURRENT ANALYSIS @ 84 METERS

FOR STATION 1109, SFB1 GOLDEN GATE BRDG ,AT THE LOCATION 37 49, 122 27
OVER THE PERIOD OF 1HR 12/11/92 TO 24H
GREENWICH PHASES ARE FOR TIME ZONE GMT

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-	
1	Z0	0.00000000	0.585	0.000	53.2	360.0	306.8	53.2	
2	MM	0.00151215	2.127	-0.098	55.2	36.3	341.1	91.4	
3	MSF	0.00282193	4.837	-0.229	121.5	205.5	84.0	327.0	
4	ALP1	0.03439657	0.748	-0.160	5.7	185.9	180.1	191.6	
5	2Q1	0.03570635	1.908	-0.127	52.6	347.2	294.6	39.9	
6	Q1	0.03721850	2.682	0.628	33.1	141.0	107.9	174.2	
7	O1	0.03873065	15.716	-0.281	1.2	152.0	150.8	153.2	
8	NO1	0.04026859	1.551	0.634	137.0	180.1	43.1	317.1	
9	P1	0.04155259	8.421	1.560	176.0	353.8	177.8	169.7	INF FR K1
10	K1	0.04178075	33.372	-1.361	-1.9	171.4	173.3	169.5	
11	J1	0.04329290	2.525	0.591	13.0	162.2	149.2	175.2	
12	OO1	0.04483084	1.232	0.126	131.0	351.9	220.9	123.0	
13	UPS1	0.04634299	1.375	-0.064	158.6	289.0	130.4	87.6	
14	EPS2	0.07617731	1.415	-0.011	48.0	297.8	249.8	345.7	
15	MU2	0.07768947	0.902	0.507	21.8	344.0	322.2	5.7	
16	N2	0.07899925	17.876	-0.545	2.9	163.0	160.1	165.9	
17	M2	0.08051140	108.207	-4.245	179.9	7.8	187.9	187.7	
18	L2	0.08202355	3.599	-0.055	135.5	7.3	231.8	142.7	
19	S2	0.08333334	23.274	-0.329	-5.2	196.7	201.8	191.5	
20	K2	0.08356149	4.713	-0.308	153.8	10.5	216.6	164.3	INF FR S2
21	ETA2	0.08507364	1.480	0.265	142.8	347.3	204.5	130.1	
22	MO3	0.11924206	7.239	-0.483	168.4	224.1	55.6	32.5	
23	M3	0.12076710	2.107	1.259	177.3	130.6	313.3	307.8	
24	MK3	0.12229215	10.344	-0.408	2.7	22.8	20.1	25.4	
25	SK3	0.12511408	3.245	-0.170	135.2	239.9	104.7	15.1	
26	MN4	0.15951064	3.463	0.419	13.1	20.2	7.0	33.3	
27	M4	0.16102280	10.393	2.867	29.4	52.2	22.9	81.6	
28	SN4	0.16233259	1.624	-0.667	139.9	233.7	93.8	13.6	
29	MS4	0.16384473	1.510	-1.059	142.1	253.6	111.5	35.7	
30	S4	0.16666667	1.180	0.169	82.6	224.1	141.5	306.7	
31	2MK5	0.20280355	5.180	-0.724	136.7	319.5	182.8	96.2	
32	2SK5	0.20844743	0.726	0.466	56.6	92.6	35.9	149.2	
33	2MN6	0.24002205	1.074	0.292	17.4	103.7	86.3	121.1	
34	M6	0.24153420	4.430	-0.709	51.7	127.0	75.3	178.6	
35	2MS6	0.24435613	1.713	1.527	98.9	209.6	110.7	308.5	
36	2SM6	0.24717808	1.671	-0.052	129.5	159.2	29.7	288.7	
37	3MK7	0.28331494	5.564	-1.089	82.5	273.1	190.6	355.6	
38	M8	0.32204559	1.403	0.514	143.1	71.0	287.9	214.1	
39	M10	0.40255699	1.372	0.780	15.7	3.3	347.6	19.1	

APPENDIX C

ROTATION TO PRINCIPAL AXIS

I. ROTATION TO PRIMARY AXIS

A. Theory

The first step in analysis of current data was to rotate the U and V components to a coordinate system which mimimizes variance along one axis. This coordinate rotation was done as follows:

$$x' = x\cos\theta + y\sin\theta$$

$$(x'^2) = x^2\cos^2 + y^2\sin^2 + 2xy\cos\theta\sin\theta$$

$$\frac{d(x'^2)}{d\theta} = 2(y^2 - x^2)\cos\theta\sin\theta + 2xy(\cos^2 - \sin^2)$$

Setting the derivative to zero

$$2(x^2 = y^2)\cos\theta\sin\theta = 2xy\cos 2\theta$$

$$(x^2 - y^2)\sin 2\theta = 2xy\cos 2\theta$$

$$\tan 2\theta = \frac{2xy}{x^2 - y^2}$$

B. MATLAB Calculations

The calculations were performed by MATLAB using the following M-file:

```
for i=1:19
    u=udata(:,i);
    v=vdata(:,i);
    u=u-mean(u);
    v=v-mean(v);
    uu=u.*u;
    vv=v.*v;
    uv=u.*v;
    theta(i)=2*mean(u.*v)/(mean(uu)-mean(vv));
    ang(i)=0.5*atan(theta(i));
    deg(i)=ang(i)*180/pi;
end
```

The files "ang" and "deg" are the radian and degree rotations required to rotate the data in each depth bin (i) to its primary axis. The numerical results are listed in Table C-1 and plotted in Figure C-1.

C. Scatter Plots

MATLAB was then used to develop scatter plots of U vs V for the rotated, de-meaned signal as follows:

```
u#=udata(:,#);
v#=vdata(:,#);
u#=u#-mean(u#);
v#=v#-mean(v#);
u=u#.*cos(ang(#))+v#.*sin(ang(#));
v=-u#.*sin(ang(#))+v#.*cos(ang(#));
plot(u,v,'.')
```

Only the odd numbered bins were analyzed so that statistical independance was ensured. The resultant data were retained for further tidal analysis.

TABLE C-1
ROTATION REQUIRED TO PRIMARY AXIS BY DEPTH BIN

Depth(m)	Bin	Degrees	Radian
12	1	3.1139	.0543
16	2	3.5607	.0621
20	3	4.6045	.0804
24	4	5.9323	.1035
28	5	7.4965	.1308
32	6	8.0997	.1414
36	7	8.3832	.1463
40	8	8.4307	.1471
44	9	8.1770	.1427
48	10	7.7075	.1345
52	11	7.0833	.1236
56	12	6.3760	.1113
60	13	5.6071	.0979
64	14	4.9788	.0869
68	15	4.4501	.0777
72	16	4.0139	.0701
76	17	3.5560	.0621
80	18	3.1358	.0547
84	19	2.5404	.0443

APPENDIX D

DE-TIDING AND RESIDUAL ANALYSIS

I. DE-TIDING PROCEDURE

To analyze the residual currents, I removed the "pure" tidal signal from the "raw" signal by subtracting the Foreman predicted constituent signal. Each Foreman derived constituent signal was found in a file named fubig# or fvbig#, where # represented the bin number. The raw data rotated to their principal axis were placed in files named u#r, where # represented the bin number. The simple MATLAB commands,

```
u#detide=u#r-fubig#;
v#detide=v#r-fvbig#;
```

were used to subtract the Foreman constituent tide signal from the raw rotated data signal. The result was a very noisy low amplitude "de-tided" current signal.

II. LOW FREQUENCY ANALYSIS

To remove the noise from the de-tided signals, and as a crude de-tiding method on CTD and other data, a Butterworth 72 hour, low pass filter was created in MATLAB as follows:

```
[b,a]=butter(5,6/(72*60); for three minute data
[b,a]=butter(5,4/(72*60); for two minute data
```

Each signal was filtered using:

```
y#=filter(b,a,<filename>);
```

Signals that were low passed included: de-tided U and V, W, moored CTD data (pressure, temperature, and salinity), winds measured at the Golden Gate Bridge, and the NOAA tide guage data.

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